

# INVERTEBRATE BIODIVERSITY AND CONSERVATION



BRISBANE  
30 JUNE 1994

MEMOIRS OF THE  
QUEENSLAND MUSEUM

VOLUME 36  
PART 1

## AN APPRAISAL OF RAPD-PCR: A NEW MOLECULAR TOOL FOR THE IDENTIFICATION OF INVERTEBRATE SPECIES

E.M. ABLETT

Ablett, E.M. 1994 06 30: An appraisal of RAPD-PCR: a new molecular tool for the identification of invertebrate species. *Memoirs of the Queensland Museum* 36(1): 1-2. Brisbane, ISSN 0079-8835.

The use of DNA probes to identify species, in particular the RAPD-PCR (random amplified polymorphic DNA by polymerase chain reaction) technique, has become widespread in microbiology, and is rapidly gaining acceptance in plants. Bands that remain constant in all individuals of a population or species can be used for identification of those groups. Once suitable primers have been determined for each group of species, large numbers of samples can be analysed rapidly and inexpensively. A major advantage of this technology is the ability to identify species from any stage in the life cycle. □ *DNA, PCR, molecular, identification, invertebrates.*

E.M. Ablett, *The Gene Library, Centre for molecular Biology and Biotechnology, University of Queensland, Queensland, 4072, Australia; 28 July 1993.*

The use of DNA probes to identify species has become widespread in microbiology, and is rapidly gaining acceptance in plants. In particular, the relatively quick and inexpensive RAPD-PCR (random amplified polymorphic DNA by polymerase chain reaction) technique has been used for species analysis and identification in many commercial cultivars, and wild species (Hu & Quiron, 1991; Chalmers et al., 1992).

Black et al. (1992) have recently amplified insect DNA using RAPD-PCR. They found species-specific and biotype-specific banding patterns in adult and nymph aphids. The technique also detected parasite and host species in parasitised aphids. Mention was made of having used the technique in hessian flies (Diptera: Cecidomyiidae), deltocephaline leafhoppers (Hemiptera: Cicadellidae), tetranychid mites (Acari: Tetranychidae) and aedine mosquitoes (Diptera: Cecidomyiidae), but only the latter case has the work been published (Kambhampati et al., 1992; Ballinger-Crabtree et al., 1992).

The polymerase chain reaction (PCR) is now one of the most widely used tools in molecular biology. Specific regions of the genome can be amplified in vitro using PCR. Two oligonucleotide primers (flanking the region to be amplified) are used to direct enzymatic synthesis of the specified region of the genomic DNA which acts as a template. When specific primers are used, a single gene can be amplified from minute amounts of target DNA to the extent that it can be visualised under ultra violet light on agarose gels, after staining with ethidium bromide. RAPD-PCR involves the use of slightly

less-specific primers that hybridise to and amplify multiple arbitrary regions of the genome (Williams et al., 1990). When this amplified DNA is separated according to size by agarose gel electrophoresis, variation of the resulting pattern of bands between individuals and populations represents genetic polymorphisms. These can be used for parentage assays and to investigate genetic variation within and between populations (Caetano-Anolles et al., 1991; Hadrys et al., 1992). Allelic variation can result in the loss of a band. This may limit genetic analysis, particularly of hybrids; but should be overcome by the ability to analyse multiple alleles. Bands that remain constant in all individuals of a population or species can be used for identification of those groups. For this application, it is not necessary to know what genes are amplified, we only require enough constant bands to distinguish species etc. In the gels of Black et al. (1992) there were typically three to six constant bands for each species. With at least 30 possible band positions distinguishable on these gels, (and up to 100 bands on silver stained polyacrylamide gels, Caetano-Anolles, et al., 1991), thousands of combinations would allow plenty of scope for species diagnostics.

The most time consuming aspect of getting the technique up and running is determining the most suitable primers for a particular group of taxa. Most of the RAPD-PCR primers trialed by Black et al. (1992) gave species specific banding patterns for the majority of species tested. It is only a matter of time before they and other workers publish sequences of primers suitable for a ranges of other taxa. Some of the primers used by Black

et al. (1992) were designed by Operon Technologies Inc., California; primers may already be available and/or being developed commercially.

Once suitable primers have been determined for each group of species, large numbers of samples can be analysed rapidly (results within 24 hours) and inexpensively (less than \$10 per sample including labour of about 2.5 hours for a batch of 20 samples) with existing molecular laboratory facilities. (A basic laboratory for these assays could be equipped for less than \$20,000).

Although PCR can be accomplished from a single cell, in practice this is difficult, and samples of tissue at least visible to the naked eye are preferable. The technique involves crushing specimens in an extraction buffer which contains detergent to solubilise macromolecules, and proteinase K to digest proteins. After 3 minutes at 95°C, the samples can be used directly for PCR, or frozen until needed (Black et al., 1992). The PCR is left to run for 12 hours (usually overnight) and the products are analysed by standard agarose gel electrophoresis. Any specimen or tissue containing nucleated cells can be used.

A major advantage of this technology is the ability to identify species from any stage in the life cycle (eg. larvae pupae, eggs etc.). The DNA sequence (and therefore the RAPD-PCR band pattern) remains unchanged throughout the life cycle, and also for all types of tissues. This will be particularly useful when morphological characteristics of particular stages make species identification difficult (eg. freshwater forms). Unknown nymphs etc. can be easily identified if they have RAPD-PCR banding patterns consistent with those of known adult specimens.

Keys based on RAPD-PCR patterns could be developed for species identification, and this process could be readily computerised. Combined with automated gel reading [eg. using Applied Biosystems Model 373A DNA Sequencing System to give computerised output of data from gels prepared from RAPD-PCR using fluorescent labelled primers (Applied Biosystems, 1992)] RAPD-PCR promises to be a major tool for species identification.

## ACKNOWLEDGMENTS

Thanks to the participants of the 'Towards Biodiversity and Conservation' conference for demonstrating the importance of examining invertebrate biodiversity, and the need for new tools to accomplish this.

## LITERATURE CITED

- APPLIED BIOSYSTEMS 1992. Fast precise fingerprinting of plant genomes. (Applied Biosystems application note 237404).
- BALLINGER-CRABTREE, M.E., BLACK, W.C. & MILLER, B.R. 1992. Use of genetic polymorphisms detected by RAPD-PCR for differentiation and identification of *Aedes aegypti* subspecies and populations. *American Journal of Tropical Medicine and Hygiene* 47: 893-901.
- BLACK, W.C., IV, DUTEAU, N.M., PUTERKA, G.J., NECHOLS, J.R., & PETTORINI, J.M. 1992. Use of the random amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) to detect DNA polymorphisms in aphids (Homoptera: Aphididae). *Bulletin of entomological Research* 82: 151-159.
- CAETANO-ANOLLES, G., BASSAM, B.J. & GRESHOFF, P.M. 1991. DNA amplification fingerprinting using very short arbitrary oligonucleotide primers. *Bio/Technology* 9: 553-557.
- CHALMERS K.J., WAUGH, R., SPRENT, J.I., SIMONS, A.J. & POWELL, W. 1992. Detection of genetic variation between and within populations of *Gliricidia sepium* and *G. maculata* using RAPD markers. *Heredity* 69: 465-472.
- HADRY, H., BALICK, M. & SCHIERWATER, B., 1992. Applications of random amplified polymorphic DNA (RAPD) in molecular ecology. *Molecular Ecology* 1: 55-63.
- HU, J. & QUIRON, C.F. 1991. Identification of broccoli and cauliflower cultivars with RAPD markers. *Plant Cell Reps.* 10: 505-511.
- KAMBHAMPATI, S., BLACK, W.C. & RAI, K.S. 1992. Random amplified polymorphic DNA of mosquito species and populations (Diptera: Culicidae): techniques, statistical analysis and applications. *Journal of Medical Entomology* 29: 939-945.
- WILLIAMS, J.G.K., KUBELIK, A.R., LIVAK, J., RAFALSKI, A., & TINGEY, S.V. 1990. DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Research* 18: 6531-6535.



## CONSERVATION OF INVERTEBRATE BIODIVERSITY: THE ROLE OF EX SITU PRESERVATION OF GENETIC MATERIAL

EFFIE M. ABLETT AND JOHN S. MATTICK

Ablett, E.M. & Mattick, J.S. 1994 06 30: Conservation of invertebrate biodiversity: the role of ex situ preservation of genetic material. *Memoirs of the Queensland Museum* 36(1): 3-6. Brisbane. ISSN 0079-8835.

Although conservation of biological diversity in situ is of primary importance, ex situ conservation is also important. Despite increased awareness of the need for habitat preservation, extinction of some species appears inevitable. If a species becomes extinct, a fragment of biodiversity is destroyed. However if its DNA is suitably preserved, all is not lost — DNA can be used to study the molecular make-up of an organism, and as a source of genes of scientific or practical value. DNA contains the information which underlies the idiosyncratic features of species and individuals — genes specify the structure of diverse molecules and control cell growth and development. From DNA sequences we can follow the tracks of evolution. This wealth of information from wild species is one of our most important resources. The introduction of gene banks to house source material and to provide databases is therefore a logical step. These will serve two functions: (a) a resource for exploring biological diversity and evolutionary history; and (b) a resource of increasing importance for the development of biotechnology. Gene banks can make DNA readily available to researchers throughout the world, to facilitate the development of molecular tools for further studies of biodiversity and to aid conservation research. □ *Gene banks, molecular biology, conservation, biodiversity, genotype, DNA storage, biotechnology.*

Effie M. Ablett & John S. Mattick, Centre for Molecular Biology and Biotechnology, University of Queensland, Brisbane, Queensland 4072, Australia; 1 September 1993.

Despite the increased awareness of the need for habitat preservation, the main issue of biodiversity conservation is not so much whether there will be significant loss of species, but rather the extent to which this can be prevented. While habitat preservation may be the immediate goal of those concerned with the preservation of biological diversity, present financial and human resources will limit this to high priority areas. In other areas, there seems little doubt that some extinction is inevitable. Particularly in the case of invertebrates, where so many microhabitats harbour such an enormous range of diverse forms, there will be significant loss of species and whole communities, some of which may disappear before they are examined in detail.

Each fragment of 'biodiversity' is the result of millions of years of evolution — a resource that is priceless to science, and of increasing economic importance as products and genes from wild species are utilised for the benefit of mankind. All of this information need not be lost when a species becomes extinct; part is contained in the genome and can be preserved if the integrity of its DNA is maintained. DNA can be thought of as an incredibly complex blueprint describing the molecular make-up of an entire living organism. DNA contains a wealth of information — intri-

cate details of the structure of molecules, control of gene expression (determining embryonic development and tissue differentiation) and even the evolutionary history of any individual.

It could be said that 'biological diversity is encoded in DNA'. DNA contains all the information which underlies the idiosyncratic features of species and individuals — genes specify the structure of diverse molecules and control cell growth and development. Because of the enormous, recent advances in molecular genetics, it is now possible to decode this information and increasingly to integrate it. At a time when the biological diversity of the planet is both actually and potentially under threat, we need to gather this information and preserve it as an information base for future generations. Even if species are lost, the information in the DNA will ultimately itself be of great intrinsic value as people start to take a molecular genetic perspective on biology, evolution, diversity and function. As we explore the diversity of these systems and identify genes that relate to interesting developmental pathways, genes that catalyse unusual biochemistries or which encode resistances or adaptive responses for particular environments, gene banks will have significant intrinsic value as scientific resources and then ultimately as biotechnological



resources. It is the information encoded in DNA that we need to keep for its own sake as a resource for science, as a resource for biotechnology, and if necessary for posterity in case the living species becomes extinct.

### DNA — THE SOFTWARE OF LIFE

In the past, because of the origins of the science, genetics has been viewed with either a biochemical perspective, or a population perspective. These intellectual trends which tend to be looking at either the biochemistry of DNA or inheritance in populations, do not consider DNA in the way that it really functions — as biological software. The analogies of all life forms with a computer are very strong. In any cell or organism, the cellular machinery, which produces RNA and protein from DNA, is analogous to hardware, being similar throughout the biosphere. DNA is then the software, the component that is put into the computer to obtain a particular output — the specific molecules, cell types and developmental processes that result in different individuals and species. There is then a different version of the software for each individual. Each version (the DNA sequence) can be considered to have an element of data (coding sequence) and an element of programming (sequences that control gene expression).

With the advent of molecular genetic techniques, this information can be read from DNA, our molecular software. These techniques use components of the cellular hardware as tools to read DNA sequences and obtain information on the structure of proteins and control of gene expression. In site directed mutagenesis and transgenic analysis the software is modified and put back into the cellular hardware, to gain information on the function of molecules, tissue differentiation and embryonic development. We can obtain still more information by comparing the DNA software (both structural and programming elements) of different individuals and species. We can thus examine the molecular basis of disease resistance and productivity of agricultural breeds, as well as the molecular basis of biodiversity. Because slight alterations in the software are inherited, pedigree analysis can be carried out by DNA fingerprinting. As the software is modified step by step over many generations we have a record of evolution and can gain information on evolutionary paths and phylogenetic relationships. There is a wealth of information and huge amounts of data stored in this software of life,

which we have only just started to explore using the recent explosion of molecular tools to read and analyse the data.

Putting all this information together, the Earth's biological database is enormous. The total number of living species is at least  $5 \times 10^7$ . Excluding viruses, genome sizes range from 600,000 base pairs in the most primitive cells (mycoplasma) through to more than  $10^{10}$  in some plants. As the latter contain a lot of repetitive DNA, an average coding content is likely to be about  $10^8$  base pairs of DNA. This means the Earth's genetic database is of the order of  $5 \times 10^{16}$  bits of information. In one sense this is an overestimate as many genes are shared in common between organisms. We are looking at variations upon themes; but the idiosyncratic variations on themes is the basis of biodiversity. What else is biological diversity but a continuum of variation on a theme, with lineages?

The biological database is probably the most important information on the planet. We need to preserve and utilise this database which can be accessed using DNA and RNA resources.

### EXPLORING BIOLOGICAL DIVERSITY THROUGH DNA SEQUENCE

The exploration of the genetic basis of life is being driven by the key models, particularly by the human genome project. Even though we do not realise it this is the first step in exploring biological diversity. It is necessary to first to understand how key models work, whether it be *E. coli*, *Bacillus subtilis*, *C. elegans*, *Saccharomyces cerevisiae*, *Drosophila*, mouse, man or *Arabidopsis*; so that the precise and detailed information we are going to gather in large amounts from all the diverse species of the planet can be integrated into some sort of structure. Around the world there are now genome projects that involve a whole range of species including insects. Once the genomes of key representatives of selected phyla within the biological spectrum have been defined there will be a very rapid lateral expansion of the knowledge base into related species. The question then becomes, 'What is different about each species?'; and we will be exploring biological diversity at its roots — at the genetic level. We need to preserve DNA for the future exploration of diversity. In that context in our part of the world there are many invertebrate species not yet identified, as well as many species that are highly endangered. It is not just a question

of scientific exploration, but getting to these species before they disappear.

#### GENE BANKS — PRESERVATION OF GENOTYPE

When dealing with preserved specimens, the phenotype (what we can see) is just a few percent of what is there. The unique biochemistry, mechanisms of cell differentiation and embryological development, phylogenetic position, and evolutionary history are all hidden, but written in the DNA. When a species becomes extinct, it is a tragedy if that genetic information is not preserved. Gene banks and *ex situ* collections of DNA are not going to replace phenotypic collections. In order to understand the genotype, molecular studies need to be integrated with extensive studies of phenotypes and habitats. In many parts of the world, there are well established institutions collecting invertebrate samples, and we have benefited from these locally. It is important that those organisations collect and preserve genes as well.

There has been some criticism of museums and herbaria in the past that they are just mausoleums, but if they are treated as genetic reservoirs, a more active face is provided for these collections. It is important that in any natural history collection, the DNA is preserved along with the physical phenotype. It is critical that collections from new environments (tropical, antarctic etc.) should be done in such a way that we collect DNA in a preserved form as well as samples of phenotype. We do not know what is going to happen in the next century. It would be such a tragedy if we were to walk into a museum in 50 years time and know that in the majority of samples the DNA was degraded.

What is the most useful form in which to store genotype? It would be ideal to preserve all specimens as viable germplasm, so that whole organisms could be obtained relatively easily. A limited amount of frozen material (whole organisms in the case of microfauna, eggs, ova and sperm) could then be used to produce large amounts of material from interbreeding of whole organisms. Although storage of sperm from domestic animals and seed storage from commercial cultivars has been well characterised, when it comes to sperm, eggs, whole organisms and embryos from a wide range of invertebrate species, there is such a variation of physiology from one species to another that considerable research is required to determine viable storage

conditions for each species. The difficulty and cost in collecting sperm or ova samples from many species also makes this impractical for comprehensive gene banks.

Tissue cultured cells stored in liquid nitrogen remain viable if regenerated every 5 to 10 years. Lymphoblastoid cell lines can be cultured to produce large amounts of human material, however suitable viruses need to be found to transform cells from other species. Cultured skin or muscle cells (fibroblasts) may be useful for other species, but obtaining suitable fresh skin samples is difficult. These may require considerable research to determine culture conditions for each new species. Storage of viable nuclei in any of the above forms should allow the regeneration of whole animals at some stage in the future.

The main drawback with storing tissues is that DNA is degraded by long term storage. Freezing should slow down this degradation considerably, but degradation is evident in DNA purified from mammalian blood samples that were stored at  $-60^{\circ}\text{C}$  for 2 years. Accidental thawing will also result in degradation of DNA in these samples. There is not much known about long term storage of purified DNA. Once purified free of any detectable protein, any nuclease activity will be greatly reduced or non existent. Accidental thawing for short periods will not result in any significant degradation of DNA. This is the most preferable form for long term storage and has been adopted by the Gene Library (Mattick, Ablett & Edmonston, 1992). It may be preferable to keep DNA hydrated and we routinely store our samples in T.E. or 80% Ethanol. Purified DNA can be amplified by preparation of genomic libraries to provide unlimited amounts of material for future use. In this form it can be easily disseminated to other researchers. It may be possible to regenerate whole organisms from DNA or sequence data at some stage in the future.

#### USES OF PRESERVED GENETIC MATERIAL

As well as providing the raw material for molecular studies of biodiversity, gene banks facilitate this research in other ways. When raw materials are easily obtained from a central collection, new research is readily initiated, especially when the collection of samples in the field is time consuming, and requires some expertise. *In vitro* amplification allows the same sample to be used by countless workers, and eliminates the need for repeated sampling from wild species

(which could seriously threaten a restricted population). The availability of cloned genes will facilitate DNA sequencing studies and the development of DNA probes. These tools are revolutionising basic whole organism studies, as well as applied research. Species specific DNA probes are being used increasingly for species identification (Black et al., 1992). DNA probes directed against polymorphic sites in the genome provide new means for analysing the genetic diversity of populations in the wild. Such information is crucial to the development of rational conservation strategies. Hopefully, the use of DNA from the gene banks will generate many more such applications of DNA technology in wildlife research and management in the near future. DNA sequencing is now being used to explore invertebrate diversity, determine phylogenetic relationships and define speciation, as well as giving some insights into evolution (Crozier, 1992).

Many organisms have unusual features and biochemistries, which have developed to ensure survival in specialised environments. We are only just starting to utilise these results of millions of years of evolution. Wild species of the plant kingdom are providing information and genes to produce antibiotics, anti-cancer agents, diuretics, anti-parasite compounds, hormones, anaesthetics, cardiac and respiratory stimulants, and muscle relaxants. The exploration of the invertebrates for products useful to mankind is only just beginning (Beattie, 1994). With their enormous diversity of forms and function, the invertebrates promise to be an even more valuable resource than plants.

Although largely unaware of the scientific importance of the invertebrates, the general public is interested in new scientific developments that affect their everyday lives. Products of economic importance from invertebrates may be the key to improving the public image of the invertebrates. This in turn will lead to a higher profile for invertebrate research within the government and other bodies responsible for funding. There also needs to be a change in the public image of the invertebrate scientist from a figure sitting at a microscope counting hairs on a beetle's leg to someone out in the field, at the forefront of monitoring biodiversity and changes in the environment. Although traditional systematics is, and will, always be a major tool, its use in conjunction with the latest technologies, and production of invertebrate products useful to mankind

will facilitate an improvement in the public image of invertebrate scientists.

Technologies for the manufacture of biological products are becoming increasingly orientated to molecular systems. DNA from wild species, as the raw material for these industries, will become an increasingly important resource. Today, only a tiny percentage of the earth's organisms have been examined for their use in medicine and biotechnology. It is imperative to preserve DNA of unexplored species for future applications.

## CONCLUSION

Biodiversity can be likened to a variation upon evolutionary themes. Each individual is unique and each species is unique, but there are relationships between. If one were to take a molecular biology perspective on biodiversity, it is going to be seen not as a series of absolutely unique genes or individuals, but as the individuals being unique because of the combination of their genes. As in music or art, a great symphony or a great painting is put together from a musical notes or colours which are just combinatorially rearranged. There is a whole spectrum of possibilities of colours and sounds but it is the combinations of them that make the painting or symphonies. This is what life is about. We need to preserve the molecular genetic information which tells us what combinations were made. Who knows what value that information will be in the future.

## LITERATURE CITED

- BEATTIE, A.J. 1994. Invertebrates as economic resources. *Memoirs of the Queensland Museum* 36: 7-11.
- BLACK, W.C., IV, DUTEAU, N.M., PUTERKA, G.J., NECHOLS, J.R. & PETTORINI, J.M. 1992. Use of the random amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) to detect DNA polymorphisms in aphids (Homoptera: Aphididae). *Bulletin of entomological Research* 82: 151-159.
- CROZIER, R.H. 1992. Molecular methods for insect phylogenetics. Pp. 164-221. In Oakeshott, J. & Whitten, M.J. (eds), 'Molecular approaches to fundamental and applied entomology'. (Springer-Verlag: New York).
- MATTICK, J.S., ABLETT, E.M. & EDMONSON, D.L., 1992. The Gene Library - preservation and analysis of genetic diversity in Australasia. Pp. 15-36. In Adams, R.P. & Adams, J.E. (eds), 'Conservation of plant genes: DNA banking and in vitro biotechnology'. (Academic Press: San Diego).



## INVERTEBRATES AS ECONOMIC RESOURCES

ANDREW J. BEATTIE

Beattie, A.J. 1994 06 30: Invertebrates as economic resources. *Memoirs of the Queensland Museum* 36(1): 7-11. Brisbane. ISSN 0079-8835.

The application of evolutionary biology and related disciplines (ecology, natural history, systematics and natural products chemistry) to the search for new invertebrate resources is yielding an array of novel products from a variety of unexpected sources. While this application is not new, (for example, it has been the basic paradigm in the search for biological control agents), it is under-utilised and hence undervalued. Recent examples with proven or potential commercial applications include: antibiotics and termiticides from ants, high tensile fibres from spiders, venoms from mites, spiders and scorpions for pesticide development and medicine, new adhesives from barnacles and velvet worms, novel construction materials from deep sea molluscs and a wide variety of invertebrates suitable for pharmaceuticals and biomonitoring of water and soils. These and many other examples demonstrate that (i) the deductive power of evolutionary biology and its related disciplines is of commercial importance, (ii) invertebrates in general are proving to be vital biological resources likely to yield many new products and services, and, therefore, (iii) in addition to the ecological and ethical reasons for the conservation of invertebrates, economic considerations independently highlight the folly of failing to make invertebrates the focus of major conservation efforts.

□ *Invertebrates, resources, economics, evolutionary biology.*

Andrew J. Beattie, *Research Unit for Biodiversity and Bioresources, School of Biological Sciences, Macquarie University, NSW 2109; 2 August 1993.*

*That is the one point I think all evolutionary biologists are agreed upon, that it is virtually impossible to do a better job than an organism is doing in its own environment (Lewontin, 1967).* This quotation begins a re-examination of the concept of the application of evolutionary biology to the discovery of useful biological resources. Having reviewed its current use I will then apply it to the invertebrates.

Human beings have taken advantage of adaptations in a general way for thousands of years whenever animals and plants have been used or harvested for many different kinds of products including food, fibre, medicines and building materials. However, more recently, the search for adaptations has been far more explicit and systematic. There are two areas in particular where this is true: biological control and biological monitoring (DeBach & Rosen, 1991; Holdway, 1991). The procedures required to find a biological control agent are very familiar. An enemy of the pest in question is sought, usually in the home range of the pest. The enemy may be a parasite, parasitoid, fungus, bacterium or a gene, for example, for resistance. The main objects of the search, however, are the particular adaptations that enable the control agent to attack and destroy the pest species.

The search is usually explicitly for an adaptation or a set of them. For example, a lepidopteran

larva pest may be controlled by a parasitoid wasp. The biologists involved then seek out wasp species that exhibit the appropriate life-history and behavioural adaptations. The actual search usually has a hierarchical structure, first identifying the correct geographic area, then the habitat, vegetation type, and finally the individual plant species and even particular tissues such as the flowers or leaves. A similar kind of protocol has been occurring in the search for organisms that may serve as biological monitors, in particular, in ecotoxicological studies. Here, the demand is for continuous, accurate, cost-effective sampling across broad areas. In some cases, the search for the appropriate adaptations has been articulated in evolutionary terms: which organisms are adapted to sampling media or substrates continuously as part of their normal metabolism and behaviour? Many organisms spring to mind: in aquatic and marine environments a wide range of invertebrate, larval filter-feeders, many kinds of molluscs, protozoans and fish. There is a lot of research in Australia, and elsewhere in the world, to find the species with the most appropriate adaptations for particular monitoring tasks and a great variety of invertebrates have been proposed - crustacea, bivalves, echinoderms, polychaetes and oligochaete worms, and some species are already sacrificing their lives to the cause (Holdway, 1991; Anon, 1989). Individuals are

taken to the lab and either the whole organism or selected tissues used for analysis.

At this point it is appropriate to reflect that because of the social and commercial demand for biological control and monitoring agents, an enormous range of organisms, notably invertebrates, are either potential or proven biological resources. This may appear obvious to some biologists but it is not at all obvious to most people. In fact, the idea is usually regarded as positively bizarre. Yet, crazy as it may seem, organisms as humble and diverse as parasitoid wasps, predatory beetles, invertebrate filter-feeders, and polychaete and oligochaete worms are positively and profitably biological resources. Therefore, no matter how small or obscure, pretty or ugly, these organisms must be counted along with trees, soils and fish stocks as resources requiring conservation and careful management.

#### AN EXAMPLE OF THE EVOLUTIONARY APPROACH

The evolutionary paradigm has yielded many biological resources but its potential is such that we have not yet seen much more than the tip of the iceberg especially for the invertebrates. There is no mystery here. What the biological control and biomonitoring researchers have asked, either explicitly or implicitly is: 'Where would we expect the appropriate adaptations to have evolved?'

This is an immensely powerful question. My own research is an on-going example. The increasing levels of antibiotic resistance among human pathogens is reaching truly frightening proportions and pharmaceutical companies are searching for completely new kinds of molecules. We started by asking the question: 'Where would we expect antibiotics to have evolved?' There is one familiar answer that the drug companies know about: among soil fungi competing with each other for resources by diffusing chemicals toxic to other microorganisms.

However, there are many other answers prompted by this question. One of our answers proceeds as follows: Antibiotics may be expected to evolve: (i) wherever the risk of disease by contagion is greatest which is likely to be (ii) in aggregations of animals such as breeding grounds, feeding flocks, and over-wintering aggregations, or perhaps most likely (iii) wherever animals live together permanently, (iv) in large numbers, such as insect societies, especially those that are (v) highly organised and (vi) where

the young are kept together. This reasoning points towards the insect societies including the ants. Research has shown that the bull ant *Myrmecia gulosa* possesses a pair of glands, the metapleural glands, that secrete materials with antibiotic properties. Recent assays of both crude secretions and selected fractions have revealed interesting patterns of antimicrobial activity (Veal et al., 1992; Beattie et al., 1986). The molecules responsible for the antibiotic activity are potent and appear to be unusual. The research has been supported by the Australian Government and by a multinational pharmaceutical company.

The importance of this example is to show that once the basic evolutionary question was posed, a hierarchy of questions and deductions based on natural history knowledge was possible and this process identified a target group of organisms. Evolutionary biology identified a previously unsuspected source of antibiotic substances.

The great advantage of evolutionary biology and its associated disciplines — natural history, ecology, genetics, systematics and natural products chemistry — is that it provides an organised structure and vast database that opens up entirely new horizons together with a rationale that enables us to focus on that habitat, group or family of organisms, behaviours, interactions, tissues or products most likely to merit commercial exploration. This should increase the efficiency with which potential new products are located. In the words of the old axiom: 'The secret of finding something is knowing where to look'.

In the laboratory, the process has been taken further by seeking other groups with life-history traits that suggest the evolution of antibiotics: we have collected metapleural secretions from central American leaf-cutting ants that cultivate a single species of fungus for food, actively suppressing large numbers of bacteria and fungal species that otherwise contaminate their cultures. Also, we have selected termite species using the following criteria that suggest the likelihood of the presence of antibiotics: large colony size, nest structures that aggregate individuals rather than dispersing them, distinct nurseries for juveniles, presence of food stores and long-lived adults. Our first data demonstrate that there is clear regulation of the microbiota in termite nests.

#### INVERTEBRATES AND THE EVOLUTIONARY PARADIGM

There are many more examples where the evolutionary paradigm might be used in the

search for antibiotics and other bioactive materials. However, I would like to illustrate how broad the application may be by the use of two very different examples: biominerals and spider silk.

The first area of interest is structural engineering. In one case the question asked was: 'Where would you expect the evolution of materials that were both structurally rigid yet with some degree of flexibility?' Careful reasoning then pointed to the shells of certain deep-sea molluscs and their ultrastructure provided the stimulus for new man-made materials now used in car parts and new types of concrete (Webb et al., 1991).

In a very different area, the ceramics industry has been analysing mollusc shells and radulas for the control of crystallisation processes, especially where there are specific and complex additives that must be incorporated into the final product. The radula, for example, may be hardened with iron oxides that are incorporated into the final structure to make an extremely hard surface. Engineers have been studying how molluscs accomplish this (Webb et al., 1991).

This area is rapidly growing into an industry and has already produced a journal called 'Biomimetics' with articles such as: 'Metallized nanotubules derived from bacteria'. As Derek Birchall of ICI recently wrote: 'Biology does not waste energy manipulating materials and structures that have no function and it eliminates those that do not function adequately and economically. The structures that we observe work and their form and microstructure has been developed and refined over millions of years. .... it is well, then, to look for fresh insights to biology at the wisdom encapsulated in the materials it uses' (Birchall, 1989). This is a re-statement of the theory of evolution by natural selection in the words of a materials engineer.

The second example is the uses being found for spiders, their silk and their venoms. Some kinds of spider produce silk that snares large, fast-flying prey with minimal damage to the projectile or the web. The combined properties of low weight, small diameter, extreme strength and the ability to absorb large amounts of kinetic energy are widely sought after (Vollrath & Edmonds, 1989). One recent application is bullet-proof vests filled with spider silk. There are currently several research labs figuring out, with considerable imagination, how to obtain huge quantities of spider silk for industrial applications (Helton, 1990; Beard, 1992).

The special properties of some spider venoms that paralyse rather than kill appear to have great potential for microsurgery where nerves and their associated muscles must be kept inert for short periods (Walker, 1991). In another area, the genes that produce venoms are being sought for incorporation into viruses - especially baculoviruses - that attack insects. The viruses would then be applied to crops as pesticide sprays. A similar role is being found for the venoms of scorpions and predatory mites (Tomalski & Miller, 1991; Stewart et al., 1991). Notwithstanding that these novel methods of pest control have some serious ecological and epidemiological problems, not least the lack of specificity, they illustrate the subtly and versatility with which the evolutionary paradigm can be put to use.

In each of the spider examples, there is a basic evolutionary question: in what circumstances, or under which conditions of natural selection, would the desired kinds of silk or venom have evolved?

Evolutionary biology has identified a variety of potential or proven invertebrate biological resources: cryoprotectants from collembola and mites (Lee et al., 1993), nematodes and mites for biocontrol (Gerson & Smiley, 1990), sea slugs and nematodes for brain research (Amit, 1990; Chalfie and Wolinsky, 1990), termiticides from ants (Augereau, 1988), ant-repellants from ants and wasps (Jeanne et al. 1983; Anderson et al., 1991), leeches for anti-coagulants (Sawyer, 1986; Biopharm<sup>®</sup>), bird-repellants from Hemiptera (Mason et al., 1991), biological control of weeds (McEvoy et al., 1991) and animal pests (Tumlinson et al., 1993), adhesives from Onychophora (N. Tait, pers. comm.) and annelids (Gaill et al. 1991) and a variety of invertebrates for biological monitoring (Rosenberg & Resh, 1993; Peakall, 1992) and biological control (DeBach & Rosen, 1991).

These examples include a significant proportion of the invertebrate groups, especially the largest: the Nematoda, Insecta, Chelicerata, Annelida, Crustacea, Mollusca and Echinodermata. As a consequence it is reasonable to assert that they are biological resources and that biologists have a well-established and rigorous discipline to find them and put them to use.

## INVERTEBRATE CONSERVATION

These examples not only demonstrate the importance of the conservation of invertebrates, but the conservation of invertebrate species. This is



because most of the adaptations sought are the products of individual genomes that code for precisely that life-history, behaviour, product, bioactive compound or interaction that is required. The biological control of *Salvinia* in Australia is a superb example. One species of weevil was a failure while another, almost identical weevil was a roaring success (Room, 1990).

In all of these cases the basic resources are genes that come in packets called species. Those who advocate that the conservation of biodiversity is only possible by the conservation of entire landscapes, ecosystems and communities are correct. However, it would be wise not to lose sight of one crucial reason for this — the resource potential of the genes, the species, they harbour. The mere maintenance of ecosystem function will not achieve this.

Finally, writers have agonised over the reasons for conserving species, knowing that many, perhaps most people, are persuaded only by utilitarian arguments rather than moral, ecological or ethical ones (Ehrenfeld, 1988; Randall, 1991). I share this concern but have come to the conclusion that like it or not the world will remain a market place and that, at the very least, the instrumentalist argument should be fully explored.

To be sure, only a small fraction of species are ever likely to be useful in a direct sense (Lawton, 1991), but exploration of biodiversity using the evolutionary paradigm is revealing previously unimagined applications almost daily. This raises the question: have the utilitarian arguments been seriously underestimated, especially for the invertebrates? When it comes to arguing for the conservation of invertebrates the ethical arguments still have first place and arguments for the role of invertebrates in ecosystem function may well come second. However, the utilitarian arguments for the discovery of new invertebrate resources have been poorly explored so far. Many of the examples presented here are serious in the sense that they are already commercial ventures. In other words, invertebrates already have a proven track record as biological resources in the strict commercial sense. They will become even more important as evolutionary ecology is applied to a widening range of human problems. The following quotation below remains as true today as it was 300 years ago: 'All we have yet discovered is but a trifle in comparison with what lies hid in the great treasury of nature.' Antoni van Leeuwenhoek (1680).

## LITERATURE CITED

- AMIT, D.J. 1990. 'Modelling brain function'. (Cambridge University Press: Cambridge).
- ANDERSON, A.N., BLUM, M.S. & JONES, T.H. 1991. Venom alkaloids in *Monomorium "rothsteini"* Forel repel other ants: is this the secret to success by *Monomorium* in Australian ant communities? *Oecologia* 88:157-160.
- ANON. 1991. Biological monitoring. Pp. 71-125. In 'Alligator Rivers Region Research Institute. Annual Research Summary 1988-89'. (Australian Government Printing Office: Canberra).
- AUGEREAU, J.F. 1988. Natural insecticide derived from ants. *The Guardian*, July 17, p. 14.
- BEARD, J. 1992. Warding off bullets by a spider's thread. *New Scientist* 136:18.
- BEATTIE, A.J., TURNBULL, C.L., HOUGH, T. & KNOX, R.B. 1986. Antibiotic production: A possible function for the metapleural glands of ants (Hymenoptera: Formicidae). *Annals of the Entomological Society of America* 79:448-450.
- BIRCHALL, J.D. 1989. The importance of the study of minerals to materials technology. Pp. 491-509. In Mann, S., Webb, J. & Williams, R.J.P. (eds), 'Biomimetalization: chemical and biochemical perspective'. (Verlagsgesellschaft: Hamburg).
- DEBACH, P. & ROSEN, D. 1991. 'Biological control by natural enemies'. (Cambridge University Press: New York).
- EHRENFELD, D. 1988. Why put value on biodiversity? Pp. 212-216. In Wilson, E.O. (ed), 'Biodiversity'. (National Academy Press: Washington D.C.).
- GAILL, F., WIEDEMANN, H., MANN, K., KUHN, K. & TIMPL, R. 1991. Molecular characterization of cuticle and interstitial collagens from worms collected at deep sea hydrothermal vents. *Journal of Molecular Biology* 221:209-223.
- GERSON, V. & SMILEY, R.L. 1990. 'Acarine Biological Agents'. (Chapman & Hall: Melbourne).
- HELTON, D. 1990. Web of Steel. In Burkhead, M. (Producer), Greene, B. (Narrator) 'Wildlife Tales' (audiovisual). (ABC/Kane Productions: New York, N.Y.).
- HOLDWAY, D.A. 1991. Mining and the tropical freshwater environment: Laboratory studies. *Australian Biologist* 4:228-236.
- JEANNE, R.L., DOWNING, H.A. & POST, D.C. 1983. Morphology and function of sternal glands in polistine wasps (Hymenoptera: Vespidae). *Zoomorphology* 103:149-164.
- LAWTON, J. 1991. Are species useful? *Oikos* 62:3-4.
- LEE, R.E. Jr., LEE, M.R. & STRONG-GUNDERSON, J.M. 1993. Insect cold-hardiness and ice nucleating active microorganisms including their potential use for biological control *Journal of Insect Physiology* 39:1-12.
- LEWONTIN, R.C. 1967. Spoken remark. Pp.579. In Moorhead, P.S. & Kaplan, M (eds), 'Mathemati-

- cal Challenges to the Neo-Darwinian Interpretation of Evolution'. (Wistar Institute Symposium).
- McEVOY, P., COX, C. & COOMBS, E. 1991. Successful biological control of ragwort, *Senecio jacobaea*, by introduced insects in Oregon. *Ecological Applications* 1(4):430-442.
- MASON, J.R., NEAL, J., OLIVER, J.E. & LUSBY, W.R. 1991. Bird-repellant properties of secretions from nymphs of the azalea lace bug. *Ecological Applications* 1:226-230.
- PEAKALL, D. 1992. 'Animal biomarkers as pollution indicators'. (Chapman & Hall: London).
- RANDALL, A. 1991. The value of biodiversity. *Ambio* 20:62-68.
- ROOM, P.M. 1990. Ecology of a simple plant-herbivore system: biological control of *Salvinia*. *Trends in Ecology and Evolution* 5:74-79.
- ROSENBERG, D.M. & RESH, V.H. 1993. 'Freshwater biomonitoring and benthic macroinvertebrates'. (Chapman & Hall: London).
- SAWYER, R.T. 1986. Leeches. New roles for an old medicine. Wards Natural Science Est. Inc. Rochester, New York. Spring Bulletin.
- STEWART, L.M.D., HIRST, M., FERBER, M.L., MERRYWEATHER, A., CAYLEY, P.J. & POSSEE, R.D. 1991. Construction of an improved baculovirus insecticide containing an insect-specific toxin gene. *Nature* 352:85-88.
- TOMALSKI, M.D. & MILLER, L.K. 1991. Insect paralysis by baculovirus-mediated expression of a mite neurotoxin gene. *Nature* 352:82-85.
- TUMLINSON, J.H., LEWIS, W.J. & VET L.E.M. 1993. How parasitic wasps find their hosts. *Scientific American* 266:46-52.
- VEAL, D.A., TRIMBLE, J.E. & BEATTIE, A.J. 1992. Antimicrobial properties of secretions of the metapleural glands of *Myrmecia gulosa*. *Journal of Applied Bacteriology* 72: 188-194.
- VOLLRATH, F. & EDMONDS, D.T. 1989. Modulation of the mechanical properties of spider silk by coating with water. *Nature* 340:305-307.
- WALKER, G. 1991. Spider venom could help stroke victims. *New Scientist* 130:17.
- WEBB, J., EVANS, L.A., ST. PIERRE, G. & MACEY, D.J. 1991. Biominerals: Source and inspiration for novel advanced markets. *Search* 22:137-139.

## THE VICTORIAN FLORA AND FAUNA GUARANTEE ACT: FLAGSHIP LEGISLATION FOR INVERTEBRATE CONSERVATION

RHONDA J. BUTCHER, PAM E. CLUNIE & ALAN L. YEN

Butcher, R.J., Clunie, P.E. & Yen, A.L. 1994 06 30. The Victorian *Flora and Fauna Guarantee Act*: Flagship legislation for invertebrate conservation. *Memoirs of the Queensland Museum* 36(1): 13-19. Brisbane. ISSN 0079-8835.

Current knowledge of Australian invertebrates is very limited and there is a desperate need to rectify this. Some of the existing legislation regarding invertebrate conservation is based on the incorrect premise that collecting is the major threatening process and that its control is the main way to conserve invertebrates. Such legislation seriously inhibits the attainment of knowledge that collecting facilitates. In Victoria, the *Flora and Fauna Guarantee Act* 1988 has greatly benefited invertebrate conservation through increased funding for surveys and research. More importantly, the Act has made government agencies more aware of their responsibilities and increased public awareness and participation in invertebrate conservation programs. □ *Invertebrate, conservation, legislation, flagship, Victoria, Australia.*

Rhonda J. Butcher, State Water Laboratory, Rural Water Corporation of Victoria, 590 Orrong Rd, Armadale, Victoria 3143, Australia; Pam E. Clunie, Flora and Fauna Branch, Department of Conservation and Natural Resources, 250 Victoria Parade, East Melbourne, Victoria 3002, Australia; Alan L. Yen, Invertebrate Survey Department, Museum of Victoria, 71 Victoria Crescent, Abbotsford, Victoria 3067, Australia; 4 August 1993.

Until recently, invertebrates have not been seriously considered as worthy of conservation. There are many reasons for this, including a relatively poor understanding of our native invertebrate fauna. Moreover, invertebrates have a severe public image problem — at best, they are maligned and misunderstood; at worst, totally ignored. These perceptions exist in educational institutions, the general public and conservation agencies. A concerted effort is needed to redress this 'persona non grata' status.

Historically, wildlife protection legislation has not aided the invertebrate conservation cause and, in many cases, it has been misleading and often detrimental. Deficiencies in protective legislation in Australia have centred on the protection of individual specimens rather than habitat protection, control of threatening processes, and the conservation of rare and endangered species (Rawlinson, 1981).

Legislation that promotes the protection of specimens is often based on the false assumption that collecting is the major threatening process (Yen & Butcher, 1994). The actual effects of collecting, however, are minor compared with the effects of alteration and destruction of habitats. The value of protecting invertebrate species and not their habitats is, at the very least, dubious.

In most cases, 'protection' is not synonymous with conservation, and often not effective. The

priorities for species known to be at risk should be appropriate recovery plans that include legal protection; identification and alleviation of the causes of decline; and public education and involvement. Most effort for invertebrate conservation needs to be directed at the habitat level rather than at the single species level. Even passive habitat protection, such as establishment of reserves — while an important first step — might be inadequate unless there is active management to reduce the causes of decline (Warren, 1992).

The question is then: Can protective legislation be of benefit to the conservation of invertebrates? It is our opinion that the *Flora and Fauna Guarantee* legislation passed by the Victorian Government in 1988 has the potential to be extremely beneficial, particularly in terms of promoting of invertebrate conservation awareness and actually achieving on-ground improvements. The *Flora and Fauna Guarantee* should not be viewed just as legislation, but more as an approach to conservation.

### SIGNIFICANT NEW FEATURES OF THE FLORA AND FAUNA GUARANTEE ACT

The *Flora and Fauna Guarantee Act* (hereafter FFG Act) aims to guarantee that Victoria's flora and fauna can survive, flourish and retain their potential for evolutionary



development in the wild.

The significant feature of the FFG Act compared with past or existing wildlife legislation is that it can allow for the protection of habitat. It allows for the recognition of ecological communities as entities able to be protected.

It has long been recognised that there are too many invertebrate taxa for a single species approach to invertebrate conservation to be successful for most species. Funding is generally limited and therefore prohibitive of this approach. The most widely accepted or touted method for conserving invertebrates is to protect their habitat (New, 1984).

The protection of ecological communities is an approach to invertebrate conservation that has perhaps been underestimated. By conserving a community of organisms there is an umbrella affect that guarantees the inclusion of a greater variety of taxa, including unknown taxa. This then is truly a preventative approach for ensuring the continued survival of species and the conservation of biodiversity.

Another approach is to prevent or at least reduce the direct and indirect impacts of potentially threatening processes (PTPs) on invertebrate habitat. The identification of PTPs and the implementation of management practices aimed at removing or reducing these threats is a key way of conserving flora and fauna, including invertebrates.

Before the advent of the FFG Act, wildlife protection in Victoria was controlled by the *Wildlife Act 1975*. The potential to list invertebrates for protection under the *Wildlife Act* did exist. This, however, was extremely difficult to do. For example a number of attempts were made to list the invertebrates from the IUCN Red Data Book (Wells et al., 1983), but these were all unsuccessful. Once any species of fauna is listed under the FFG Act, it is automatically protected under the *Wildlife Act*.

A problem with many types of legislation is that they have not allowed for valid research into appropriate management requirements of protected taxa. The FFG Act is not prohibitive of research because bona fide researchers are able to obtain permits to work on listed taxa and add their findings to the information base.

The final significant new feature of the Act is the emphasis on public participation. Active involvement of land owners and members of the general public is encouraged because conservation is not restricted to nature reserves. The ultimate success of the FFG Act, and other relevant

conservation legislation, will depend on public involvement. In this, the potential of the FFG Act to significantly enhance understanding of invertebrate conservation is considerable.

## KEY COMPONENTS OF THE ACT

### NOMINATION PROCESS (LISTING — DELISTING)

The FFG Act aims to guarantee the survival of the State's flora and fauna through a process of listing of threatened species, communities, and PTPs. The FFG Act covers all native taxa: the only exceptions being those specifically excluded such as human disease organisms. Any taxon or community or PTP may be nominated for listing by any individual or organisation.

Once a nomination is made, the Scientific Advisory Committee (SAC) considers the validity of the nomination based only on scientific evidence, and a preliminary recommendation is advertised widely in the print media. After a period for public comment, the SAC considers any additional scientific information provided in submissions. A final recommendation is made to the Minister as to whether or not the nomination should be listed.

*Listing* is the process by which nominated items can be added or removed from Schedules of the FFG Act. It should be noted that the Minister has the ultimate power to accept or reject any recommendation made by the SAC.

*Delisting* is the process whereby listed taxa and communities that are subsequently found to be no longer under threat — or PTPs that no longer pose a threat — are recommended to be removed from the Schedules. The process is basically the same as for listing with any individual or organisation being able to nominate an item for delisting.

### SCIENTIFIC ADVISORY COMMITTEE

The FFG Act established an independent SAC, which is made up of seven government and non-government scientists with expertise covering a range of relevant disciplines. It is the SAC's responsibility to advise the Minister for Natural Resources of nominations for listing, and on other relevant conservation issues when requested to do so by the Minister. The SAC is appointed by, and only answerable to, the Minister.

### ROLE OF THE MINISTER

The principal role of the Minister with regard to the FFG Act is to give the final approval or

disapproval for the listing of an item. So far all the recommendations made by the SAC have been accepted by the Minister.

#### THE DEPARTMENT

Although the Department of Conservation and Natural Resources (DCNR) is the agency responsible for enforcing the legislation, other public authorities are required to have regard for the objectives of the FFG Act. The main improvement associated with this, in terms of invertebrate conservation, is that DCNR is required to include invertebrates as part of its charter.

#### ACTION STATEMENTS

Action statements are perhaps the most crucial part of the FFG Act, in that they focus attention on what needs to be done, and outline management requirements. DCNR has to prepare an action statement for all listed items, and should consider socio-economic factors as well as scientific evidence. Any interested groups can request to be involved in the preparation of the action statement. When an action statement is prepared it gives guidance to both the general public and conservation staff for action priorities. Action statements are written as public documents that are designed for both land managers and the general public.

An action statement provides a summary of the current available information on the listed item; identifies areas where more information is required; outlines action required to obtain this information; identifies the necessary people who should be involved in this process; and finally specifies recommended management actions based on all the relevant information obtained. Action statements are reviewed so that additional information can be considered as it comes to light, and to assess the success of management recommendations that have been implemented.

A common misunderstanding surrounding the FFG Act is the confusion between the listing process and subsequent management. The SAC only considers nature conservation issues when assessing the eligibility of a nomination for listing. Management of listed items, including socio-economic issues, is the responsibility of DCNR and other land managers.

#### CRITICAL HABITAT

The FFG Act allows for determination of critical habitat for listed items, although it is not mandatory. DCNR broadly defines critical habitat to include areas considered necessary to

the survival and recovery of the taxon or community. The inclusion of areas that cannot currently support a population of the taxon or community may also be necessary.

#### INTERIM CONSERVATION ORDERS

An Interim Conservation Order (ICO) is a mechanism by which immediate and comprehensive protection can be enforced. An ICO may only be made by the Minister after appropriate socio-economic factors have been taken into consideration. Should loss of income or some other damaging effect occur as a result of the ICO then compensation is payable. Before an ICO may be enforced a critical habitat must be determined.

ICOs are intended to be used as a last resort. The fact that none have been made indicates the successful implementation of the FFG Act, with its emphasis on education and cooperation, rather than strict legal controls.

#### THE STRATEGY

The FFG Act required the preparation of a Strategy that sets out how the objectives for flora and fauna conservation and management are to be achieved. A draft Strategy was released in 1992 for public comment (Department of Conservation and Environment, 1992).

#### CONSEQUENCES FOR INVERTEBRATE CONSERVATION

##### ATTITUDES AND RESPONSIBILITIES

There are two important positive impacts the FFG Act has had on DCNR. Firstly, as mentioned earlier, invertebrates can now be recognised as wildlife and perforce have to be included in the main charter of DCNR. This did not happen until 1990, when the FFG Act was actually empowered in Regulations.

Secondly, DCNR is now committed to collecting information on vertebrates, plants and invertebrates together. The importance of invertebrates in the big picture is beginning to be realised.

A drawback to the relatively sudden inclusion of invertebrates on the conservation agenda in Victoria is that there is a severe shortage of staff with invertebrate training in DCNR who actually work on invertebrate-related issues. The consequence of this is that when relevant conservation work regarding invertebrates is required, it often has to be contracted out.

## PUBLIC PARTICIPATION

The FFG Act has been designed to encourage public participation. Opportunities for the public to become involved in the process are present in the processes of nominating and delisting. During the preparation of action statements, all relevant land owners likely to be affected should be consulted. Community involvement is also solicited where the FFG Act allows for public comment. The following FFG Act activities are all subject to public comment: preliminary recommendations for listing; management plans; conditions of ICOs; and any subsequent compensation arrangements.

The Eltham Copper Butterfly (*Paralucia pyrodiscus lucida*) rose to prominence as a conservation issue in the outer Melbourne suburb of Eltham in the late 1980s (New, 1991). The butterfly had been found in the Eltham area since 1938, but had undergone a steady decline and was believed to have become locally extinct. In 1987 a number of colonies were found and conservationists called for protection. A considerable publicity campaign and fundraising effort ultimately resulted in the purchase of a small area of private land, previously destined for subdivision. These activities, along with policy initiatives, resulted in the protection of key habitat

areas for the butterfly (Ahern, 1993).

Continued enthusiasm for the protection of this small butterfly exists with the 'Friends of the Eltham Copper Butterfly Group', which participates in monitoring the population of butterflies in the Eltham area. The Land for Wildlife scheme, a DCNR initiative, is also involved with land holders in the Eltham area who believe that they have butterfly habitat on their property (Ahern, 1993).

The Giant Gippsland Earthworm (*Megascolides australis*) is one of the world's largest earthworms and is restricted to a relatively small area in South Gippsland (Yen et al., 1990). It is listed in the IUCN Red Data book as Vulnerable (Wells et al., 1983). This relatively unattractive invertebrate has received considerable attention from local communities in the Bass River Valley. The local Shire has been supportive of research on the worm and sponsored an exhibit at the Coal Creek Historical Park. There is also an annual festival named after the worm which takes place in Korumburra (Yen, 1993). Land for Wildlife has been successful in encouraging local land owners to participate in the conservation of the species by producing a pamphlet that outlined how to recognise and protect the worm's habitat (Van Praagh, 1991; Yen, 1993).

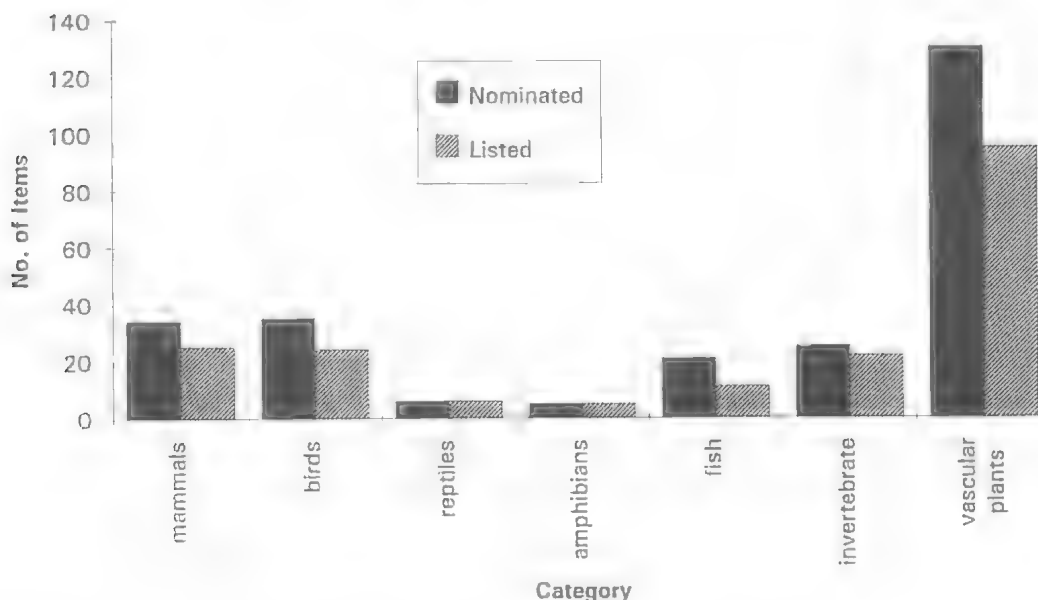


FIG. 1. Breakdown of nominations and listed taxa according to major taxonomic categories.



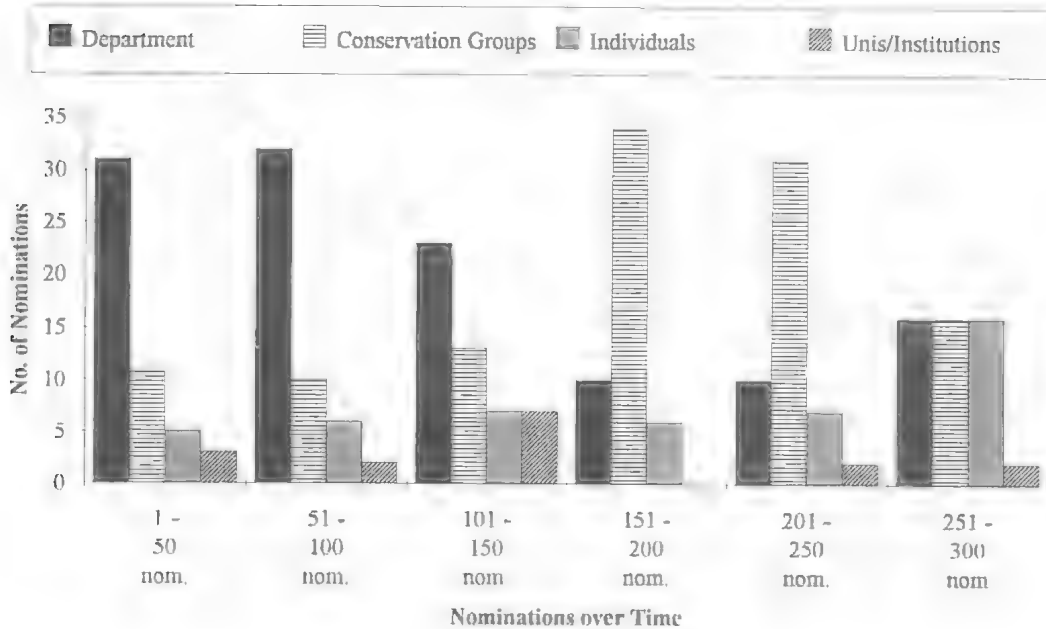


FIG. 2. Breakdown of nominations, in 50 unit blocks, made under the *Flora and Fauna Guarantee Act* by various organisations.

From this example, it is evident that cooperation with land owners is preferable to imposing strict legal controls on them. Furthermore, the public interest in the Giant Gippsland Earthworm indicates that it is not necessary to have an attractive species as a flagship taxon for invertebrate conservation.

An invertebrate community known as Butterfly Community No. 1 on Mt Piper in Victoria has also received considerable support from the local community and council (Jelinek et al., 1994).

#### MISCONCEPTIONS ABOUT THE FFG ACT

One of the problems encountered in the FFG Act is that people try to stop development at a particular site by basing the nomination around the site. However a site cannot be listed unless it contains a threatened taxon or community. An example of this can be seen from the nomination and subsequent rejection of the Altona Skipper Butterfly (*Hesperilla flavescens flavescens*). Many lepidopterists considered the butterfly to be of significant conservation value, but through the nomination process it became evident that the butterfly was more widespread than originally believed (Crosby, 1990), and the only site threatened was Altona. A further attempt was made to protect the local population at Altona by

proposing a site-based nomination for special consideration: this was also rejected (SAC, 1991a,b).

#### ACHIEVEMENTS

So far a total of 321 nominations have been received by the SAC. Of the nominated items, the majority have been accepted with only 46 being ineligible or invalid. Many of the taxa listed have been vascular plants and the only delisted taxon was also a vascular plant (Table 1).

When the nominations and listed taxa are broken down into taxonomic groupings, the number of invertebrates listed is encouraging, and comparable to that of the major vertebrate groups (Fig. 1).

Apparently, invertebrates protected in other States have mainly been collectable, attractive insects such as butterflies and jewel beetles. With Victorian invertebrates, 20 non-marine and two marine taxa, and one non-marine and one marine community have been listed under the FFG Act. Action statements for the listed invertebrates have either been published or are in preparation.

Only a few of the listed taxa are butterflies, none of which are highly prized as collectable

TABLE 1. Numbers of nominations received and assessed by the Scientific Advisory Committee, Flora and Fauna Guarantee.

	Taxa	Communities	Potentially Threatening Processes
No. of Nominations	265	34	22
No. of Listed	191	14	12
No. of Ineligible	16	8	2
No. of Delisted	1	0	0
No. of Invalid	13	7	0

TABLE 2. Invertebrates listed under the *Flora and Fauna Guarantee Act 1988*.

TAXA
bull ant <i>Myrmecia</i> sp.17
Small Brown Azure Butterfly <i>Ogyris atanes</i>
Large Ant-blue Butterfly <i>Acrodipsas brisbanensis</i>
Small Ant-blue Butterfly <i>A. myrmecophila</i>
Eltham Copper Butterfly <i>Paralucia pyrodiscus lucida</i>
Hemiphysbia Damselfly <i>Hemiphysbia mirabilis</i>
Giant Gippsland Earthworm <i>Megascolides australis</i>
marine opisthobranch <i>Rhodope</i> genus
marine opisthobranch <i>Platydoris galhana</i>
freshwater amphipoda <i>Austrogammarus australis</i>
Orbost Crayfish <i>Euastacus diversus</i>
Otway Stonefly <i>Eusthenia nothofagi</i>
caddisfly <i>Archaeophylax canarius</i>
stonefly <i>Riekoperla isosceles</i>
stonefly <i>R. intermedia</i>
Mt Donna Buang Wingless Stonefly <i>R. darlingtoni</i>
Alpine Stonefly <i>Thaumatoperla flaveola</i>
stonefly <i>T. alpina</i>
planarian <i>Spathula tryssa</i>
Warragul Burrowing Crayfish <i>Engaeus sternalis</i>
Mallacoota Burrowing Crayfish <i>E. mallaconta</i>
Narracan Burrowing Crayfish <i>E. phyllocercus</i>
COMMUNITIES
San Remo Marine Community
Butterfly Community No.1

items (Table 2). The remainder of the listed invertebrates are not collectable species in terms of desirability.

Overall, the highest number of nominations has come from DCNR and conservation groups (Fig. 2). An interesting point is that universities are not

nominating many items, which is perhaps unexpected and of concern. Individuals are nominating more items over time, perhaps reflecting an increasing awareness of the FFG Act.

## CONCLUSION

The *Flora and Fauna Guarantee Act* should be viewed as flagship legislation for native flora and fauna, especially for taxa that are usually omitted from the conservation agenda. As with most legislation, the FFG Act is not perfect, but it can be used to successfully wave the flag for invertebrate conservation in a number of ways. The most important are the recognition of invertebrates as wildlife and the raising of public awareness of them. The success of conservation of invertebrates in Victoria will ultimately depend on community support for the FFG Act. The results so far are very encouraging.

## ACKNOWLEDGEMENTS

We thank Julia Reed for assistance and helpful comments on the FFG Act, and Peter Lillywhite for assistance in preparation of this paper.

## LITERATURE CITED

- AHERN, L.D. 1993. Eltham Copper Butterfly — 'The people's choice'. Land for Wildlife Note No. 21. (Department of Conservation and Environment: Melbourne).
- CROSBY, D.F. 1990. 'A management plan for the Altona Skipper Butterfly *Hesperilla flavescens flavescens* Waterhouse (Lepidoptera: Hesperidae)'. Arthur Rylah Institute for Environmental Research Technical Report Series No. 98. (Department of Conservation, Forests & Lands: Victoria).
- DEPARTMENT OF CONSERVATION AND ENVIRONMENT 1992. 'Draft Flora and Fauna Guarantee Strategy: Conservation of Victoria's biodiversity'. (Department of Conservation and Environment: Melbourne).
- JELINEK, A., BRITTON, D.R. & NEW, T.R. 1994. Conservation of a threatened butterfly community. *Memoirs of the Queensland Museum*, 36: 115-120.
- NEW, T.R. 1984. 'Insect conservation — an Australian perspective.' (W. Junk Publishers: Dordrecht).
1991. 'Butterfly conservation.' (Oxford University Press: Melbourne).
- RAWLINSON, P.A. 1981. Conservation of

- Australian amphibian and reptile communities. Pp. 127-138. In Banks, C.B. & Martin, A.A. (eds), 'Proceedings of the Melbourne Herpetological Symposium'. (The Zoological Board of Victoria: Melbourne).
- SAC (SCIENTIFIC ADVISORY COMMITTEE, FLORA AND FAUNA GUARANTEE) 1991a. 'Final recommendation on a nomination for listing: *Hesperilla flavescens flavescens* Waterhouse — Altona Skipper Butterfly (Nomination No. 147)'. (Department of Conservation and Environment: Victoria).
- 1991b. 'Final recommendation on a nomination for listing: Salt-pan/Marshland and Butterfly Community. (Nomination No. 148)'. (Department of Conservation and Environment: Victoria).
- VAN PRAAGH, B.J. 1991. Giant Gippsland Earthworm — "Nature's plough." Land for Wildlife Note No. 11. (Department of Conservation and Environment/Bird Observers Club of Australia: Melbourne).
- WARREN, M.S. 1992. The conservation of British butterflies. Pp. 246-274. In Dennis, R.L.A. (ed.), 'The ecology of butterflies in Britain.' (Oxford University Press: Oxford).
- WELLS, S.M., PYLE, R.M. & COLLINS, N.M. (compilers). 1983. 'The IUCN invertebrate Red Data Book.' (IUCN: Gland).
- YEN, A.L. 1993. The role of museums and zoos in influencing public attitudes towards invertebrate conservation. Pp. 213-229. In Gaston, K.J., Samways, M. & New, T. (eds), 'Perspectives in insect conservation'. (Intercept Ltd: Andover, Hampshire).
- YEN, A.L. & BUTCHER, R.J. 1994. 'An overview of the conservation status of non-marine invertebrates in Australia'. (Endangered Species Unit, Australian Nature Conservation Agency: Canberra).
- YEN, A.L., NEW, T.R., VAN PRAAGH, B. & VAUGHAN, P.J. 1990. Invertebrate Conservation: Three case studies in Southeastern Australia. Pp. 207-224. In Clark, T. & Secbeck, J.H. (eds), 'Management and conservation of small populations'. (Chicago Zoological Society: Brookfield, Illinois).

## THE INTRODUCED NORTHERN PACIFIC SEASTAR *ASTERIAS AMURENSIS* IN TASMANIA

ROGER E. BUTTERMORE, ELIZABETH TURNER AND MARGARET G. MORRICE

Buttermore, R.E., Turner, E. & Morrice, M.G. 1994 06 30: The introduced northern Pacific seastar *Asterias amurensis* in Tasmania. *Memoirs of the Queensland Museum* 36(1): 21-25. Brisbane. ISSN 0079-8835.

In early 1992 the northern Pacific seastar, *Asterias amurensis* was identified from Tasmanian waters. It is possible that larvae may have been released in discarded ballast water from overseas ships. Each adult female may release up to 19,000,000 eggs annually. The species is a serious predator of accessible marine fauna, particularly bivalve molluscs. Little is known of the impact of *A. amurensis* on its northern hemisphere habitat. The seastars appear to be thriving in Tasmanian waters and vast numbers have been observed around the Hobart waterfront. Research by the Tasmanian Museum includes surveys of present distribution and abundance of the seastar, data about its physico-chemical environment, aspects of its reproductive biology, and the species on which it preys. Future management of this pest in Australia may well depend on the information provided by this research. □ *Asterias amurensis*, ballast water introductions, Echinodermata, Asteroidea, aquaculture, alien species, Tasmania, Australia.

Roger E. Buttermore, Elizabeth Turner & Margaret G. Morrice, Tasmanian Museum, Hobart, Tasmania 7001, Australia; 30 March 1994.

Recently the northern Pacific seastar *Asterias amurensis* has become established in southeastern Tasmanian waters. As a significant predator with high fecundity it is of particular concern to scientists, environmentalists and the aquaculture/fishing industries.

Larvae of the species may have been released in Tasmanian ports by the discharge of ballast water from bulk carriers. Intolerance of warmer water makes it unlikely that *A. amurensis* travelled through tropical latitudes by natural locomotion or on the hulls of ships (Munday et al., 1993). Two other recent introductions, a Japanese seaweed *Undaria pinnatifida* and a toxic dinoflagellate *Gynodinium catenatum*, have already been linked to ballast water discharge. All three alien species currently are found around some Tasmanian port areas (Jones, 1991; Zeidler, 1992).

Seastars from Rosny Point in the Derwent River estuary were lodged with the Tasmanian Museum in October 1986, but were misidentified as the native seastar *Uniophora granifera*. The two species are very similar in appearance. The increase in the number of seastars was originally attributed to repopulation of *U. granifera* in a cleaner Derwent River, as a result of a reduction in effluent discharged by industries.

In 1992 Dr Wolfgang Zeidler of the South Australian Museum was sent a specimen and noticed that it did not conform to any known Tasmanian (or mainland Australian) species. Dr

Loisette Marsh of the Western Australian Museum positively identified samples from Tasmania as *A. amurensis* (Turner, 1992).

### DISTRIBUTION

The natural distribution of *A. amurensis* extends around the coast of Japan to Russia and through the Bering Sea. Reports of *A. amurensis* in Alaska and Canada are considered by Russian scientists to be the result of another accidental introduction (McLoughlin & Bax, 1993).

In Tasmania *A. amurensis* is found mainly in the waters of southeastern Tasmania. To date it has been sighted several kilometres upstream and downstream of Hobart, in Frederick Henry Bay, down the D'Entrecasteaux Channel to the Huon River estuary and on the east coast of Tasmania near Triabunna (Fig. 1). The seastars have been found in scallop spat bags, in mussel and oyster farms, and feeding on mussels living on the netting of salmon farm pens. They have also been reported in recreational fishing nets in the Derwent River where they have stripped the flesh off captured fish. From diving surveys in southeastern Tasmania the species is known to occur on various substrates including mud, sand and rock, and in water depths from littoral to 30 metres (Morrice, 1993). Surveys are currently underway by Tasmanian Museum staff to estimate the abundance of the seastar throughout its distribution.

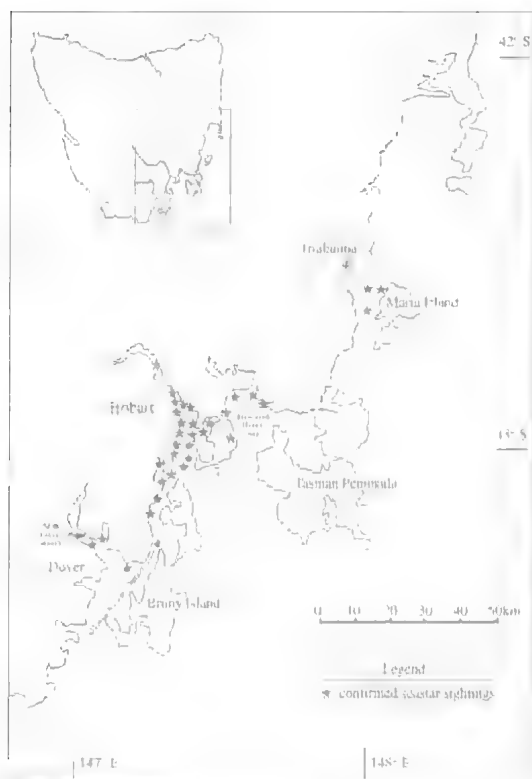


FIG. 1. Known distribution of the northern Pacific seastar *Asterias amurensis* in Tasmanian waters: based on confirmed sightings, diving and dredging surveys to mid-November 1993.

A computer simulation of egg and larval dispersal in Tasmania by Lyne (1993) predicts extensive spread of the seastar. Using biological information gathered from Japanese sources (Hawkes & Day, 1993) combined with Tasmanian wind data from 1988, the model forecasts dispersal to northern Tasmania and beyond. However, other factors such as temperature, food, substrate and mortality which would affect survival and settlement are yet to be included in the simulations.

#### SEXUAL REPRODUCTION, GROWTH AND POPULATION DYNAMICS

*Asterias amurensis* is dioecious. Ovaries in ripe females are large with microscopic eggs (diameter 110–150 µm) and each female may spawn up to 19,000,000 eggs annually (Kim, 1968; Kasryanov, 1988). Some *A. amurensis* females dissected in Hobart are so full of eggs

from July to September that their gonads extend into the stomach cavity.

In Japan the main spawning event occurs during the winter-spring season from January to late April, peaking in late February (Takashi et al., 1955; Kim, 1968). In Tasmania, mean gonad indices indicate a major spawning event also occurs in winter-spring, peaking in early August (Fig. 2) (Morrice, 1993). Further sampling and histological information, particularly prior to the onset of spawning, will enable a more accurate assessment.

Fertilisation is external and larvae hatch into a short gastrula stage and develop through a free pelagic period. The length of the larval stage is still uncertain, however laboratory tests have cultured bipinnaria larvae for 40–60 days (Sagura & Ino, 1954; Kasryanov, undated).

Once the juvenile seastar has settled growth is rapid and it may mature in one year with a ray length of about 40 mm (Kim, 1968). In Tasmania, gonads are present in seastars with a ray length greater than 55 mm (Morrice, 1993). The largest specimen recorded thus far in Tasmania had a ray length of 203 mm. In contrast, the largest record mentioned in available literature about northern Pacific specimens had a ray length of 192 mm (Oguro, 1991). As with other *Asteriidae* species, damaged ray regeneration is common. New seastars can grow from severed rays if a piece of the central disc is still attached (Marsh, 1993).

In its northern Pacific habitat, particularly in the southern range, large variations in population density occur in three or ten year cycles, depending on the location. The density of seastars during these outbreak periods is approximately 4–6 m<sup>-2</sup> (Nojima et al., 1986). The outbreaks can last for

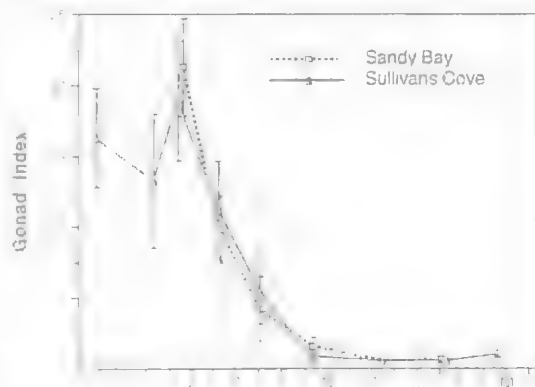


FIG. 2 The mean gonad index ( $\pm 95\%$  confidence limits) for *Asterias amurensis* at Sullivan's Cove and Sandy Bay, Tasmania from June 1993 to March 1994.





FIG. 3. Typical feeding aggregation of *A. amurensis* on the mussel *Mytilus edulis planulatus*. Photograph by Bill Denholm.

two or three years. During these times the seastars swarm together in masses on the seabed, and particularly on any available food. In the docks at Hobart, the mean abundance of seastars at Macquarie Wharf in August 1993 at a depth of 10m was  $9.44\text{m}^{-2}$ . The highest concentrations occur on dumped fish carcasses (an illegal practice) and live mussels (Fig. 3).

#### FEEDING

Tasmanian Museum researchers have observed *A. amurensis* feeding on bivalve and gastropod molluscs, barnacles, crabs, other crustaceans, brittle-stars, worms, sea cucumbers, other seastar species (including their own kind), ascidians, and drowned dogs. The stomach is everted to digest a food item. *Asterias amurensis* is an opportunistic feeder but will select certain prey if available. Japanese studies have shown that the preferred prey are mussels and oysters with a shell height equal to the length of the seastar's ray (Kim, 1969b; Park & Kim, 1985). Bivalve molluscs are eaten after the shells have been prised apart by the

rays. *Asterias amurensis* will dig shallow pits in search of buried prey depending on prey depth (Kim, 1969a). Feeding aggregations of other *Asterias* species release chemical stimuli which attract their own kind (Zafiriou, 1972; Hawkes & Day, 1993).

#### SEASONAL VARIATIONS

Anecdotal evidence has suggested a seasonal migration of *A. amurensis* in Japan (Nojima et al., 1986). In Tasmania preliminary research has begun to establish whether the seastars undergo migration from shallow to deeper water in the summer to avoid warmer water. Surveys are being conducted in various depths at three sites to test for significant changes in abundance. Already a change in mean abundances of seastars has been recorded at a depth of 10 m at Macquarie Wharf, Hobart, from  $9.44\text{m}^{-2}$  in August 1993 to  $2.33\text{m}^{-2}$  in December 1993 (Morrice, 1993).

## POSSIBLE DAMAGE TO ECOLOGY AND INDUSTRY

In the northern hemisphere *A. amurensis* is a serious predator on commercial scallops and a threat to the trawl-fishing industry (Hatanaka & Kosaka, 1959; Kim, 1968). Japanese and Russian studies of the species have concentrated on its physiology, biochemistry and embryology but no specific research on its ecology has been undertaken. McLoughlin & Bax (1993) note an apparent low biodiversity off the temperate Russian coast, but this may not necessarily be attributed to *A. amurensis*. The ongoing effect on ecology by the seastar in southern Tasmania is being measured in diving surveys conducted by the Tasmanian Museum recording the number and diversity of the seastar's prey species. As there are no baseline data on biodiversity in areas where *A. amurensis* has already become established, it is therefore very difficult to measure its impact on the original ecology of these communities.

## CONTROL MEASURES

No fully effective solutions to the population outbreaks in the northern Pacific have been found apart from localised trapping and dredging at marine farms in Japan (McLoughlin & Bax, 1993). There is also little recorded evidence in Japan and Russia on natural predators, parasites or diseases apart from accounts of predation by the seastar *Solaster paxillatus*, and the presence of a parasitic gastropod and ciliophoran (McLoughlin & Bax, 1993). Russian scientists have observed the Alaskan King crab *Paralithodes camtschatica* preying on *A. amurensis* in an aquarium (Mikulich & Benulina, 1972).

As the population outbreak of *A. amurensis* is relatively contained to the southeast Tasmanian region, immediate short term controls should be implemented in addition to research into long term biological controls to prevent the seastar spreading further. Recommendations provided so far on short term control measures include removal by diver, use of baited traps, and treatment of seawater being transported from affected areas particularly during and after the spawning season. Trials are currently underway on a seastar trap designed by a local fisherman to test its catch effectiveness.

In an effort to highlight the extent of the problem, to instigate action to remove the seastar and to collect information for research, the Tasmanian

Museum, in association with professional and recreational divers, held two major dives in the Hobart docks during the 1993 winter. Over 30,000 seastars were collected and donated to Dr Martin Line of the University of Tasmania for experimental composting trials. Results thus far are promising (Line, pers. comm.).

## CURRENT RESEARCH

A 16 month research program for 1993-94 is being funded by the Feral Pests Program of the Australian Nature Conservation Agency. The grant is the first awarded for study of an introduced marine pest. Two researchers are currently employed full-time by the Tasmanian Museum in Hobart.

Assistance in determining the extent of distribution has been sought from the public, aquaculture farmers and fishermen. A pamphlet has been available from the Tasmanian Museum since 1992 to assist people to distinguish between the native species *U. granifera* and *A. amurensis*, and to report sightings. An updated pamphlet is presently in production. A colour poster jointly produced by the National Seastar Task Force, the Tasmanian Museum and CSIRO Division of Fisheries to assist with identification is now available from various agencies.

## ACKNOWLEDGMENTS

We thank Bill Denholm for his photograph and are grateful for help from Adrian Spinks and Brent Dawes of the Tasmanian Museum for their production of the poster version of this paper. Thanks also to the members of the Tasmanian SCUBA Diving Club and Avril McGeary-Brown for their voluntary labour, and to Sue Marsh for access to her data and references.

## LITERATURE CITED

- HATANAKA, M. & KOSAKA, M. 1959. Biological studies on the population of the starfish, *Asterias amurensis*, in Sendai Bay. *Tohoku Journal of Agricultural Research* 9: 159-178.
- HAWKES, G & DAY, R. 1993. Review of the biology and ecology of *Asterias amurensis*. Pp. 10-29. In Davenport S. & McLoughlin R. (eds), 'Preliminary assessment of the distribution and potential impact of the introduced starfish *Asterias amurensis* in Tasmanian waters'. (Unpublished report, Fisheries Research and Development Corporation, CSIRO Division of Fisheries, Hobart, Tasmania).

- JONES, M.M. 1991. 'Marine organisms transported in ballast water. A review of the Australian scientific position', Bureau of Rural Resources Bulletin No. 11. (Australian Government Publishing Service, Canberra).
- KASYANOV, V.L. Undated. Unpublished scientific report on egg and larval development of *A. amurensis*. Marine Biology Institute, Vladivostok, 16 p. [In Russian].
1988. Reproductive strategies of sea stars from the Sea of Japan. Pp. 205-209. In Burke, R.D., Mladenov, P.V., Lambert P., & Parsley R.L. (eds), 'Echinoderm biology' (A.A. Balkema: Rotterdam).
- KIM, Y.S. 1968. Histological observations of the annual change in the gonad of the starfish, *Asterias amurensis* Lütken. Bulletin of the Faculty of Fisheries Hokkaido University 19: 97-108.
- 1969a. Selective feeding on the several bivalve molluscs by starfish, *Asterias amurensis* Lütken. Bulletin of the Faculty of Fisheries Hokkaido University 19: 244-249.
- 1969b. An observation on the opening bivalve molluscs by starfish, *Asterias amurensis*. Bulletin of the Faculty of Fisheries Hokkaido University 20: 60-63.
- LYNE, V. 1993. Modelling of the dispersal of *Asterias amurensis* eggs and larvae in Tasmanian waters. Pp. 30-38. In Davenport S. & McLoughlin R. (eds), 'Preliminary assessment of the distribution and potential impact of the introduced starfish *Asterias amurensis* in Tasmanian waters'. (Unpublished report, Fisheries Research and Development Corporation, CSIRO Division of Fisheries, Hobart, Tasmania).
- MARSH, S.J. 1993. 'The biology and distribution of the introduced sea star *Asterias amurensis*. (Lütken) (Echinodermata: Asteroidea) in Tasmania'. (Unpublished Honours Thesis, University of Tasmania, Hobart).
- MCLOUGHLIN, R. & BAX, N. 1993. 'Scientific discussions in Japan and Russia on the northern Pacific seastar'. (Unpublished report, CSIRO Division of Fisheries, Hobart, Tasmania).
- MIKULICH, L.V. & BERULINA, M. G. 1972. The behaviour of the *Asterias* seastar and the Kamchatka crab together in aquarium conditions. Hydrobiological Issues of some Areas of the Pacific: 52-54. [In Russian].
- MORRICE, M.G. 1993. 'The distribution and ecology of the introduced northern Pacific seastar, *Asterias amurensis* (Lutken) in south-eastern Tasmania'. (Unpublished progress report, Australian Nature Conservation Agency, Canberra).
- MUNDAY, B.L., DAINITITH, M., SANDERSON, J.C. & TURNER, E. 1993. 'Ballast Water Research 1993. A biological and epidemiological review of putative ballast water introductions, *Undaria pinnatifida* and *Asterias amurensis*'. (Unpublished report, Australian Quarantine and Inspection Service, Canberra; National Key Centre for Aquaculture, University of Tasmania, Launceston).
- NOJIMA, S., SOLIMAN, F.E-S., KONDO, Y., KUWANO, Y., NASU, K. & KITAJIMA, C. 1986. Some notes on the outbreak of the sea star *Asterias amurensis versicolor* Sladen, in the Ariake Sea, western Kyushu. Publications from the Amakua Marine Biological Laboratory 8: 89-112.
- OGURO, C. 1991. Asteroidea. Pp. 96-109. In Oguro, C. & Okutani, T. (eds), 'Echinoderms from Continental Shelf and Slope around Japan, Vol. II'. (Japan Fisheries Resource Conservation Association: Tokyo).
- PARK, M.S. & KIM, B.Y. 1985. Feeding behaviour of the starfish *Asterias amurensis* (Lütken). Bulletin of the Fisheries Research and Development Agency, Pusan, Korea 34: 171-174.
- SAGARA, J. & INO, T. 1954. The optimum temperature and specific gravity for bipinnaria and young of Japanese starfish, *Asterias amurensis* Lütken. Bulletin of the Japanese Society of Scientific Fisheries 20: 689-693.
- TAKASHI, I., SAGARA, J., HAMADA, S. & TAMAKAWA, M. 1955. On the spawning season of the starfish *Asterias amurensis*, in Tokyo Bay. Bulletin of the Japanese Society of Scientific Fisheries 21: 32-36.
- TURNER, E. 1992. A northern Pacific sea star, *Asterias amurensis*, in Tasmania. Australian Marine Science Bulletin 120: 18-19.
- ZAFIRIOU, O. 1972. Response of *Asterias vulgaris* to chemical stimuli. Marine Biology 17: 100-107.
- ZEIDLER, W. 1992. Introduced starfish pose threat to scallops. Australian Fisheries 51: 28-29.

## DISTRIBUTION OF PARASITIDS OF SCARAB LARVAE IN RELATION TO REMNANT VEGETATION: A PRELIMINARY ANALYSIS

A.J. CAMPBELL AND G.R. BROWN

Campbell, A.J. & Brown, G.R. 1994 06 30: Distribution of parasitoids of scarab larvae in relation to remnant vegetation: a preliminary analysis. *Memoirs of the Queensland Museum* 36(1): 27-32. Brisbane. ISSN 0079-8835.

Distribution and abundance of scarab parasitoids (families Tiphidae, Scolidae and Tachinidae) were monitored using malaise traps in remnant vegetation and at varying distances up to 400m into adjacent pasture. Preliminary results indicate lower overall parasite diversity and abundance in grazed pasture. Tiphid numbers decrease with distance from the remnant vegetation. Tachinid numbers were the highest at the forest margin and the lowest at a distance of 200m into the pasture, and increased again beyond 200m. Loss of the shrub component on farms through grazing pressure or deliberate clearing will result in a significant loss of beneficial insect biodiversity. □ *Scarabs, tiphids, tachinids, remnant vegetation, malaise traps, distribution, abundance, pasture.*

A.J. Campbell, Regional Veterinary Laboratory, N.S.W. Agriculture, P.M.B. (UNE), Armidale, New South Wales, 2351. G.R. Brown, Biological and Chemical Research Institute, N.S.W. Agriculture, P.M.B. 10, Rydalmere, New South Wales, 2116. Present Address: Museum and Art Gallery of the Northern Territory, P.O. Box 4646, Darwin, Northern Territory, 0801; 28 July 1993.

Many scarabs are important agricultural pests. Their larvae are subterranean and feed on grass roots and other organic matter. Depending on seasonal conditions, larvae may be significant pasture pests. Some adults feed on tree leaves, especially eucalypts, and in large numbers cause serious defoliation. Prolonged and repeated defoliation over a number of seasons contributes to the death of trees (Landsberg & Wylie, 1988). On the northern tablelands of NSW, leaf-feeding scarabs, mainly of the genera *Anoplognathus* and *Sericesthis*, are one cause of eucalypt dieback. Adults of some scarab genera present (*An-titrogus*, *Dasygnathus* and *Rhopaea*) do not feed at all.

Most scarabs on the northern tablelands are indigenous. Goodyer (1985) and Davidson & Davidson (1992) suggested that scarabs can be controlled by maintenance of bushland on farms to provide habitat for their predators and parasites.

There are 3000 recognised species of scarab occurring in Australia (Lawrence & Britton, 1991). Adult taxonomy is reasonably well known while that of immature stages is not. Consequently, adults and larvae of many species cannot be correlated, except in a few regional areas and specific crops (e.g. McQuillan, 1985; Rogers, Brier & Houston, 1992).

Known insect parasitoids of scarabs are dipteran Tachinidae and wasps of Scolidae and Tiphidae. Colless & McAlpine (1991) recog-

nised 542 tachinid species from Australia, but only Dexiinae and *Palpostoma* (Tachininae: Palpostomatini) are considered scarab parasites (Crosskey, 1973a, 1973b; Barraclough, 1992). The Dexiinae contains many undescribed species.

Naumann (1991) recorded 25 scoliid species from Australia. All are believed to be exclusively parasitic on scarab larvae.

About 500 species of Australian Tiphidae are named (Given, 1954). Few hosts are recorded (e.g. Burrell, 1935) for the family and it is assumed that all, except *Diamma bicolor* (a parasite of mole crickets), parasitise scarab larvae (Naumann, 1991). Their taxonomy is poorly known and papers e.g. Brown (1989) indicate that there may be at least twice as many undescribed species currently in collections. Hence, a conservative estimate is about 1500 Australian species.

Because of their diversity and abundance and their assumed host specificity, tiphids are the most important insect scarab parasitoids. Several Australian species were tried to be introduced into New Zealand to control *Costelytra zealandica* (Given, 1953). All failed to establish (Given, 1968) either because the wrong parasites were selected, or from an incomplete understanding of the host and parasite biology.

This is a preliminary study of population dynamics of parasitoids of scarab larvae. The design was to test the hypothesis that scarab parasitoids kept to the remnant vegetation with



TABLE 1. Distribution of traps and distance away from remnant vegetation.

SITE	TRANSECT	TRAP No.	DISTANCE	TRANSECT	TRAP No.	DISTANCE
<i>Daisy Hill</i>	East-west	Series 1		North-south	Series 2	
		1	—		7	—
		12	0		6	60
		5	50			
		2	100			
		3	240			
		4	280			
<i>Fairburn</i>	EW	Series 3		NS	Series 4	
		21			29	—
		22	0		28	0
		23	100		27	100
		24	200		26 <sup>b</sup>	200
		25	300			

<sup>a</sup> Distance from remnant vegetation in metres. No values are given for traps in the forest. Zero values indicate the trap is at the forest edge. <sup>b</sup> Trap 26 is at the intersection of transects 3 and 4.

little movement into the adjacent open pasture areas. These stands presumably provided shelter, food and other resources necessary for their survival. There are no detailed data on the movements of any scarab parasitoid groups in Australia, but tiphiids are not believed to move far out into open pasture (Ridsdill Smith, 1970).

## METHODS

Parasitoid numbers were monitored at two sites 50km east of Armidale at the eastern edge of the tree-decline affected area of northern NSW. These sites were 5km apart on the adjacent properties of Daisy Hill and Fairburn.

Soils at both sites were dominated by granite parent material but a small area of soils were derived from sediments at Daisy Hill, and basalt at Fairburn. The vegetation was similar at both sites. The properties have undergone similar clearing, pasture improvement and grazing regimes. At Daisy Hill the forest/pasture boundary is well defined. The forest (a mixture of vegetation types, from heath to eucalypt woodland and forest) has undergone minimal disturbance by grazing and timber removal. At Fairburn, the pasture/forest boundary is not as well defined as most of the forest has had greater

disturbance. There has been partial clearing within the remnant forest and livestock are not excluded. The transition from forest to pasture is more gradual.

Twenty malaise traps, as described by Townes (1972), were established: 8 at Daisy Hill and 12 at Fairburn. The distribution pattern of remnant vegetation allowed traps to be established only at intervals up to 400m. At each site, traps were located within the forest, at the forest edge and at intervals out into the adjacent pasture (at right angles to the forest boundary).

Traps were in 4 series based on site and transect orientation away from the remnant vegetation (Table 1.). At Daisy Hill, Trap 1 was in the forest, Trap 12 was at the forest boundary, whilst Traps 2-6 were in open pasture. Trap 7 was in a stand of leptospermum in forest otherwise free of understorey. At Fairburn, Traps 21 and 29 were in remnant vegetation areas dominated by *Eucalyptus* spp. with a variable shrub layer. Traps 23-28 were in the open and Trap 26 was at the intersection of 2 transects. Trap 29 was the only trap surrounded by an understorey of bursaria. Trap 30 was on a grazed wooded ridge top with few shrubs, over 600m away from the nearest trap (Trap 26, in open pasture). Traps 30-32 because of their location or different vegetation were not

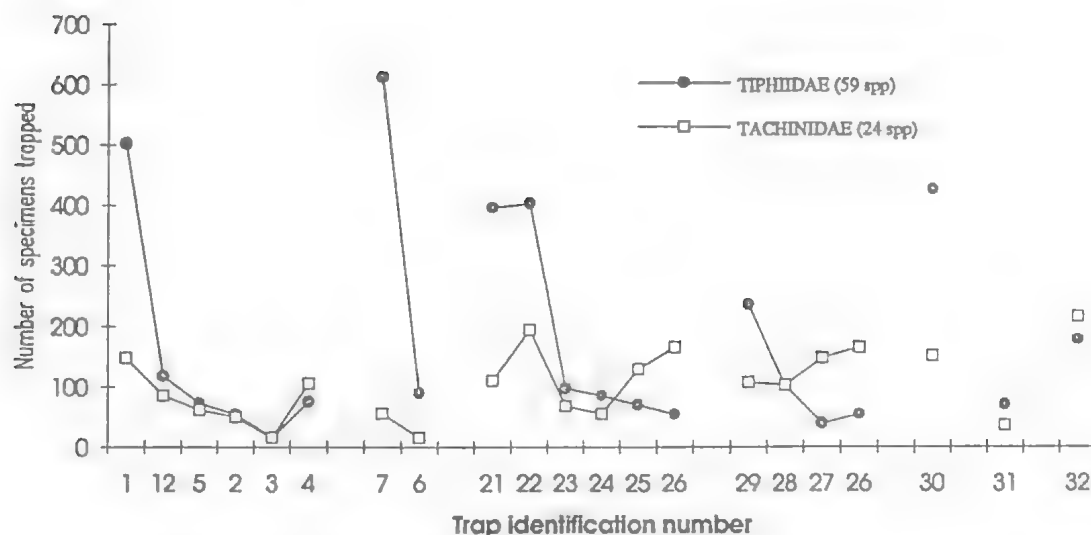


FIG. 1. Total number of Tiphid and Tachinid scarab parasitoids collected per trap.

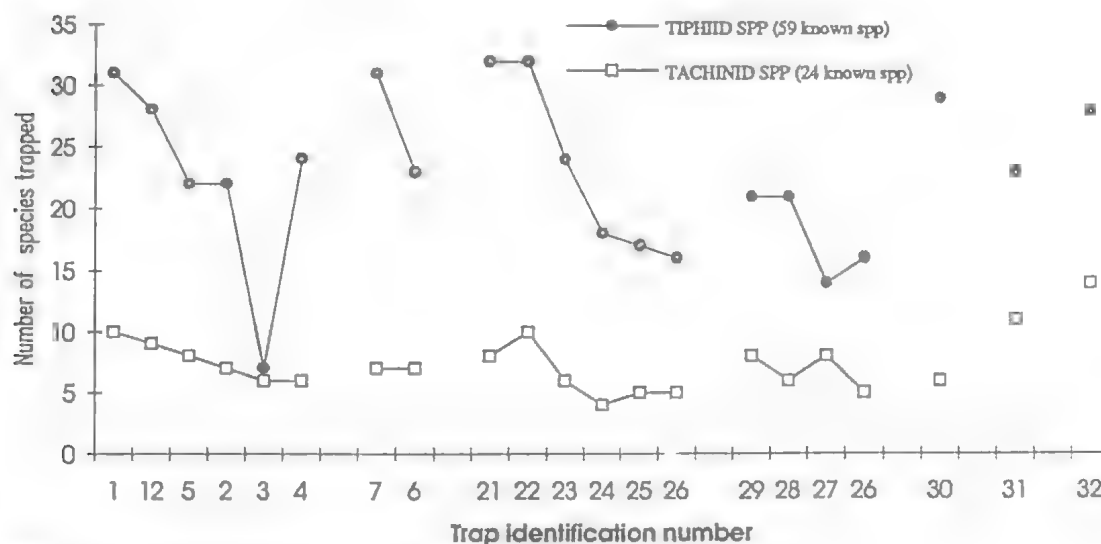


FIG. 2. Total number of Tiphid and Tachinid species caught per trap.

included in any transect. Trap 31 was in low leptospermum scrub, surrounded by tall kunzea with few eucalypts, while Trap 32 was in a small natural clearing adjacent to the leptospermum. Traps 31 and 32 were near Trap 21.

All traps had the collection vessel outlet at the northern end (1.9m above ground level) and the longitudinal axis aligned north-south. Traps were individually fenced to exclude stock and grass within the enclosures was periodically mown.

Collection vessels on the malaise traps were changed every 7 days. Spiders on trap walls were

removed to prevent predation. All adult tiphids, tachinids (including non-scarab parasitising species), scoliids and scarab beetles within the traps were retained for identification.

## RESULTS

Trapping data are presented for the period 16 August 1991-26 December 1992 (Table 2). Collected specimens were: 5311 scarab parasitoids, of which 3,274 are tiphids (excluding the grylotalpid parasite *Diamma bicolor*), 2,027 are

TABLE 2. Numbers of scarab parasitoids and scarab beetles collected.

TRAP NO.	TIPHIIDS	TIPHIIDS <sup>1</sup>	SCOLIIDS	TACHINIDS	TACHINIDS <sup>2</sup>	SCARABS	TOTAL
Daisy Hill Series 1							
1	503	496	0	541	148	30	1718
12	118	107	0	495	86	27	833
5	73	71	0	587	62	26	819
2	54	52	1	507	50	30	694
3	16	16	0	329	16	14	391
4	76	72	0	571	106	21	846
Daisy Hill Series 2							
7	612	590	1	823	56	22	2104
6	90	89	2	708	16	35	940
Fairburn Series 3							
21	396	258	0	482	111	0	1247
22	403	384	1	1839	194	0	2821
23	98	95	1	1326	68	0	1588
24	86	79	0	871	55	0	1091
25	70	63	3	742	130	0	1008
26 <sup>3</sup>	54	52	1	579	166	0	852
Fairburn Series 4							
29	236	166	0	1165	108	0	1675
28	102	81	0	824	103	0	1110
27	39	35	0	508	148	0	730
26 <sup>3</sup>	54	52	1	579	166	0	852
Fairburn							
30	427	355	0	768	152	1	1703
31	70	55	0	244	36	0	405
32	178	158	0	851	216	0	1403
TOTAL	3701	3274	10	14760	2027	206	23978

<sup>1</sup> Tiphids except *Diamma bicolor*. <sup>2</sup> Scarab parasitising Tachinids. <sup>3</sup> Included in 2 series but only once in total.

tachinids (scarab parasitising species) and 10 scoliids. At least 59 species of tiphid, 24 tachinid and 4 scoliid species have been recognised. Also, a further 14,760 non-scarab parasitising tachinids of an unknown number of species, but potentially important in controlling other pests of both pasture and trees have been retained.

Of the 87 parasitoid species recognised, at least 39 are undescribed: 28 tiphids and 11 tachinids; the incidence of undescribed species varies from very common to rare. Further breakdown to species level of tiphids (see Appendix) is not meaningful because of the large number of undescribed species.

Tiphid species' abundance using artificial frequency classes are: very common (>100 captures), 4; common (20-99), 19; uncommon

(10-19), 13; rare (5-9), 4; very rare (<5), 19 captures. The last category include 3 species not captured in Malaise traps but only by sweep netting. Tiphids were fewer along transects away from remnant vegetation (Table 2, Fig. 1).

Tiphid diversity (i.e. species richness) is higher in the forest and at the boundary with the pasture. Diversity is lower further from the remnant vegetation (except for Traps 4 and possibly 27) and the same general trend occurs in tachinids (Fig. 2). Tiphid catches, both in abundance and diversity, are lower at Trap 29 (surrounded by bursaria) than for traps near leptospermum. Tachinids appear unaffected by the dominant flowering species near the traps. Results from Trap 30 were higher than expected.

Tachinids numbers generally peak at the interface between the pasture and forest and decline immediately adjacent to the forest edge before rising again. (Fig. 1).

The complex of 87 parasitoids potentially utilise the 25 scarab species so far collected from the area.

Over 120 angiosperms (excluding Poaceae, Cyperaceae, Restionaceae, Jucaceae, Casuarinaceae) were recorded at Daisy Hill with fewer species at Fairburn. Species abundance varied across and between properties. Eucalypts did not flower during the sampling period. Parasitoids showed a general preference for low to medium height shrubs rather than prostrate plants. From sweeping and field observations, most adult parasitoids were found on leptospermum, baeckea and to a lesser extent bursaria. Regular sampling over other flowering plants (including hakea, kunzea, lomatia and epacris) gave insignificant catches.

## DISCUSSION

A difference in habitat preference between the tephritids and tachinids is suggested. Tephritids have a distinct preference for flowering shrub or reduced light situations as found in forest areas, whilst tachinids appear more sun loving and capable of utilising open pasture.

The ratio of tephritid:tachinid scarab parasitoids caught is greater than 1.6:1. Tephritids cannot be assumed to be the predominant parasitoids in the field because of differences in fecundity, potential flight behaviour and ability to be trapped.

Other apparent discrepancies in data (Series 1, Trap 4) may be due to soil texture changes, e.g. tephritids were frequently observed hawking over a flat sandy area adjacent to Trap 4. Soil samples in this area had higher counts of parasitoid pupa and scarab larvae than elsewhere in the open. Scarab larvae were more common in the open pasture than the remnant vegetation areas. Scarab populations were non-random aggregations of mixed species.

Data from Trap 31 suggest the apparent inability of parasitoids to use leptospermum surrounded by taller dense kunzea, although catches show a high level of diversity.

It became apparent early in the study that certain families e.g. Scoliidae were seldom caught by malaise traps. They were observed flying around and over the traps in summer but too few specimens were collected to allow meaningful conclusions. It is unknown what other species

avoided the traps or what proportion of the population was sampled.

The number of species found in the study highlighted the need for detailed taxonomic work in conjunction with field sampling. The similarity of some species and the number of recognisable but undescribed species creates problems if taxonomic services are not available.

Regardless of shortcomings in the technique used, there are no alternatives for continuous adult parasitoid sampling. Malaise traps returned species not collected by sweep netting once a week and the intensity of sampling should give a reliable indication of the total parasitoid biodiversity. Preliminary results indicate intensive regular sampling is necessary to pick up significant seasonal variation in both abundance and diversity of parasitoids.

To maximise parasitoids, access to appropriate flowering energy sources is needed. We found that leptospermum are the preferred species. A significant loss of beneficial insect biodiversity on farms will occur if grazing pressure or deliberate clearing destroys shrubs or forest remnants.

The results highlight the importance of adequate temporal and spatial sampling for biodiversity assessments. This study has provided data on only one phase of population dynamics of scarab parasitoids. Population recoveries after the serious drought across northern NSW will require further study and will provide a valuable contrast with these data.

## ACKNOWLEDGMENTS

This project has been possible only because of the support of the Rural Industries Research and Development Corporation who funded the project and the generous assistance of Malcolm Ross and Allan McRae who allowed unlimited access to their properties for sampling. Chris Haywood, Duncan Mackay and Bruce Turnbull assisted with data collection.

## LITERATURE CITED

- BARRACLOUGH, D.A. 1992. The systematics of the Australian Dexiini (Diptera: Tachinidae: Dexiinae) with revisions of endemic genera. Invertebrate Taxonomy 6: 1127-1371.
- BROWN, G.R. 1989. Revision of the Australian genus *Doratithynus* Turner (Hymenoptera: Tephritidae). Journal of the Australian Entomological Society 28: 1-17.
- BURRELL, R.W. 1935. Notes on the habits of certain



- Australian Thynnidae. *Journal of the New York Entomological Society* 43: 19-26.
- COLLESS, D.H. & McALPINE, D.K. 1991. Diptera (Flies). Pp. 717-786. In Naumann, I.D. (ed.), 'The Insects of Australia. A textbook for students and research workers'. (Melbourne University Press: Carlton).
- CROSSKEY, R.W. 1973a. A revisionary classification of the Rutiliini (Diptera: Tachinidae), with keys to the described species. *Bulletin of the British Museum (Natural History) Entomology*, London, Supplement No. 19.
- 1973b. A conspectus of the Tachinidae (Diptera) of Australia, including keys to the supraspecific taxa and taxonomic and host catalogues. *Bulletin of the British Museum (Natural History) Entomology*, London, Supplement No. 21.
- DAVIDSON, R. & DAVIDSON, S. 1992. 'Bushland on Farms: Do You Have a Choice'? (AGPS: Canberra).
- GIVEN, B.B. 1953. General report on a search for parasites of Melolonthinae in Australia. *New Zealand Journal of Science and Technology. Series B* 34: 322-340.
1954. A catalogue of the Thynninae (Tiphidae: Hymenoptera) of Australia and adjacent areas. *Bulletin of the New Zealand Department of Scientific and Industrial Research* 109.
1968. Resolute research to defeat grassgrubs. *New Zealand Journal of Agriculture* 116: 82-83.
- GOODYER, G.J. 1985. Scarab grubs in northern tableland pastures. Department of Agriculture, NSW. Agfact P2.AE. 1.
- LANDSBERG, J. & WYLIE, R.F. 1988. Dieback of rural trees in Australia. *Geo Journal* 17: 231-37.
- LAWRENCE, J.F. & BRITTON, E.B. 1991. Coleoptera (Beetles). Pp. 543-683. In Naumann, I.D. (ed.), 'The Insects of Australia. A textbook for students and research workers'. (Melbourne University Press: Carlton).
- McQUILLAN, P.B. 1985. The identification of root-feeding cockchafer larvae (Coleoptera: Scarabaeidae) found in pastures in Tasmania. *Australian Journal of Zoology* 33: 509-546.
- NAUMANN, I.D. 1991. Hymenoptera (Wasps, bees, ants, sawflies). Pp. 916-1000. In Naumann, I.D. (ed.), 'The insects of Australia. A textbook for students and research workers'. (Melbourne University Press: Carlton).
- RIDSDILL SMITH, T.J. 1970. The behaviour of *Hemithynnus hyalinatus* (Hymenoptera: Tiphidae), with notes on some other Thynnidae. *Journal of the Australian Entomological Society* 9: 196-208.
- ROGERS, D.J., BRIER, H.B. & HOUSTON, K.J. 1992. Scarabaeidae (Coleoptera) associated with peanuts in Southern Queensland. *Journal of the Australian Entomological Society* 31: 177-181.
- TOWNES, H. 1972. A light-weight malaise trap. *Entomological News* 83: 239-247.

APPENDIX. Provisional taxonomic status of tiphid genera collected at all sites.

Genus	No. of Species		
	Total	Described	Undescribed
<i>Agriomyia</i>	2	2	
<i>Anthobosca</i>	7	2	5
<i>Ariphron</i>	4	4	
nr <i>Ariphron</i>	2		2
<i>Asthenothynnus</i>	3	1	2
<i>Diamma</i>	1	1	
<i>Eirone</i>	7	1	6
<i>Elidothynnus</i>	1	1	
<i>Guerinius</i>	1	1	
<i>Hemithynnus</i>	2	2	
<i>Lestricothynnus</i>	1	1	
<i>Lophocheilus</i>	2		2
<i>Neozeleboria</i>	4	1	3
<i>Phymatothynnus</i>	4	1	3
<i>Rhagigaster</i>	4	4	
<i>Tachynomia</i>	5	3	2
<i>Thynnoides</i>	2	1	1
<i>Thynnoturneria</i>	2	1	1
<i>Zaspilothynnus</i>	1	1	
TOTAL	55	28	27

## SYMBIONTS AND BIODIVERSITY

LESTER R.G. CANNON AND KIM B. SEWELL

Cannon, L.R.G. & Sewell, K.B. 1994 06 30: Symbionts and biodiversity. *Memoirs of the Queensland Museum* 36 (1): 33-40. Brisbane. ISSN 0079-8835.

The importance of invertebrate symbionts to our concepts of conservation and biodiversity is demonstrated using Australian freshwater crayfish and their symbionts as a model. Concepts discussed are (1) hosts are also habitats, and (2) conserving biodiversity means conserving symbionts. The case is argued for *Euastacus* to act as 'flagships' to focus our need to preserve invertebrate species and their habitats. □ *Invertebrates, parasites, symbiosis, freshwater crayfish, Euastacus, Cherax, temnocephalan, conservation, biodiversity*

Lester R.G. Cannon & Kim B. Sewell<sup>1</sup>, Queensland Museum, PO Box 3300, South Brisbane, Queensland 4101, also: (a) Department of Parasitology and (b) Department of Anatomical Sciences, The University of Queensland, Brisbane, Queensland 4072; 6 August 1993.

Symbionts literally are organisms which live together. Attempts to define and prescribe limits to the spectrum of associations found have proven impossible (Price, 1980; Schmidt & Roberts, 1989); parasitism, however, is the most common and easily recognised form of symbiosis in which the parasite, usually the smaller organism, derives benefit from the other, the host. This account highlights the central role of invertebrate symbionts to conservation and biodiversity by using Australian freshwater crayfish and their symbionts as a model, and in doing so places symbiosis at the forefront of the current debate on conservation and biodiversity.

Many people today unfortunately still perceive most symbionts as undesirable, since they frequently compete with us for resources but in our opinion it is now time to consider an objective ecological view of the value of symbionts. Medical and agricultural science wages continual war against pests and parasites, yet van Beneden (1876), reflecting his times, cautioned that even grave diggers have a place in society. Similarly, we think we must begin to acknowledge the value to society of symbionts even though we may not always care to associate with them. We must acknowledge that the diversity of life is vastly enriched by such symbionts - most of which are invertebrates. A prerequisite to their conservation, we believe, is an extension of our concept of habitats: we must recognise hosts as habitats (Horwitz, 1990a).

### AUSTRALIAN FRESHWATER CRAYFISH

Haswell (1893) recognised 3 crayfish species on the Australian mainland. These were the spiny or mountain crayfish (*Astacopsis serratus* (Shaw,

1794)) from coastal streams of eastern Australia, the smooth crayfish of inland streams (*Astacopsis bicarinatus* Gray, 1845) and the burrowing crayfish of Victoria (*Engaeus fossor* (Erichson, 1846)).

About 100 species of crayfish on mainland Australia are now recognised (Morgan, 1988; Horwitz, 1990b; John Short, Queensland Museum, *pers. comm.*). Of these, the spiny mountain crayfish *Euastacus* spp. (formerly *Astacopsis serratus*) are without doubt the most endangered (Horwitz, 1990b). Twelve of the 24 species of crayfish listed by Horwitz (1990b) as rare and endangered, are *Euastacus*, and 10 of these are from Queensland. *Euastacus* spp. generally have specific habitat requirements *viz.*, cool, clean water in streams with good canopy cover (Horwitz, 1990b). These conditions occur in southern Australia at sea level, but in Queensland are found almost entirely in forested, mountain regions (Fig. 1; Morgan, 1988). Changing climate over geological time has clearly led to habitat restriction of the *Euastacus* spp., threatening extinction in some cases (Horwitz, 1990b). However, human influence has dramatically reduced available habitat further. Regions inhabited by *Euastacus* have yielded the finest rainforest timbers and, once cleared, proved ideal for farming dairy cattle. In Queensland, and in New South Wales according to Merrick (1993), the dairy industry has prospered at the expense of the habitat of *Euastacus*. Today, most rare and/or endangered species of *Euastacus* are restricted to National Parks or forestry regions (Horwitz, 1990b).

### CRAYFISH HABITATS

Freshwater crayfish are large and most are edible, especially the larger species of *Cherax* which are farmed for food (Merrick & Lambert, 1991). Aquaculture has driven research to determine which invertebrate symbionts (particularly parasites and pathogens) inhabit the three major food crayfish of Australia, viz. *Cherax quadricarinatus* (von Martens, 1868) (= redclaw), *C. destructor* Clark, 1936 (= yabbie) and *C. tenuimanus* (Smith, 1912) (= marron). Consequently our knowledge of the diversity of symbiont suites of cultured crayfish has increased dramatically (Table 1, a-c).

Symbionts of crayfish are diverse and numerous. From over 10,000 published references to crayfish, over 10% of them concern symbionts in 8 different phyla or groups (Hart & Clark, 1987). Furthermore, interactions within a suite of ectosymbionts using crayfish as a habitat are complex (Cannon & Jennings, 1987; Jennings, 1988).

### TEMNOCEPHALAN ECTOSYMBIONTS

Temnocephalans are the largest symbionts on crayfish. These ectosymbiotic turbellarian flatworms are particularly common on Australian crayfish and have been known for over 100 years (Haswell, 1893). On the 3 crayfish hosts that were recognised then, Haswell (1893) reported 7 species of worms. These were: *Temnocephala fasciata* Haswell, 1888 and *T. comes* Haswell, 1893, as large brown and small white species respectively on *Astacopsis serratus*, *T. minor* Haswell, 1888 as an external inhabitant and *T. dendyi* Haswell, 1893 and *Craspedella spenceri* Haswell, 1893 as gill inhabitants of *Astacopsis bicarinatus* and from *Engaeus fossor*, *T. engaei* Haswell, 1893 externally and *Actinodactylella bluncharidi* Haswell, 1893 on the gills.

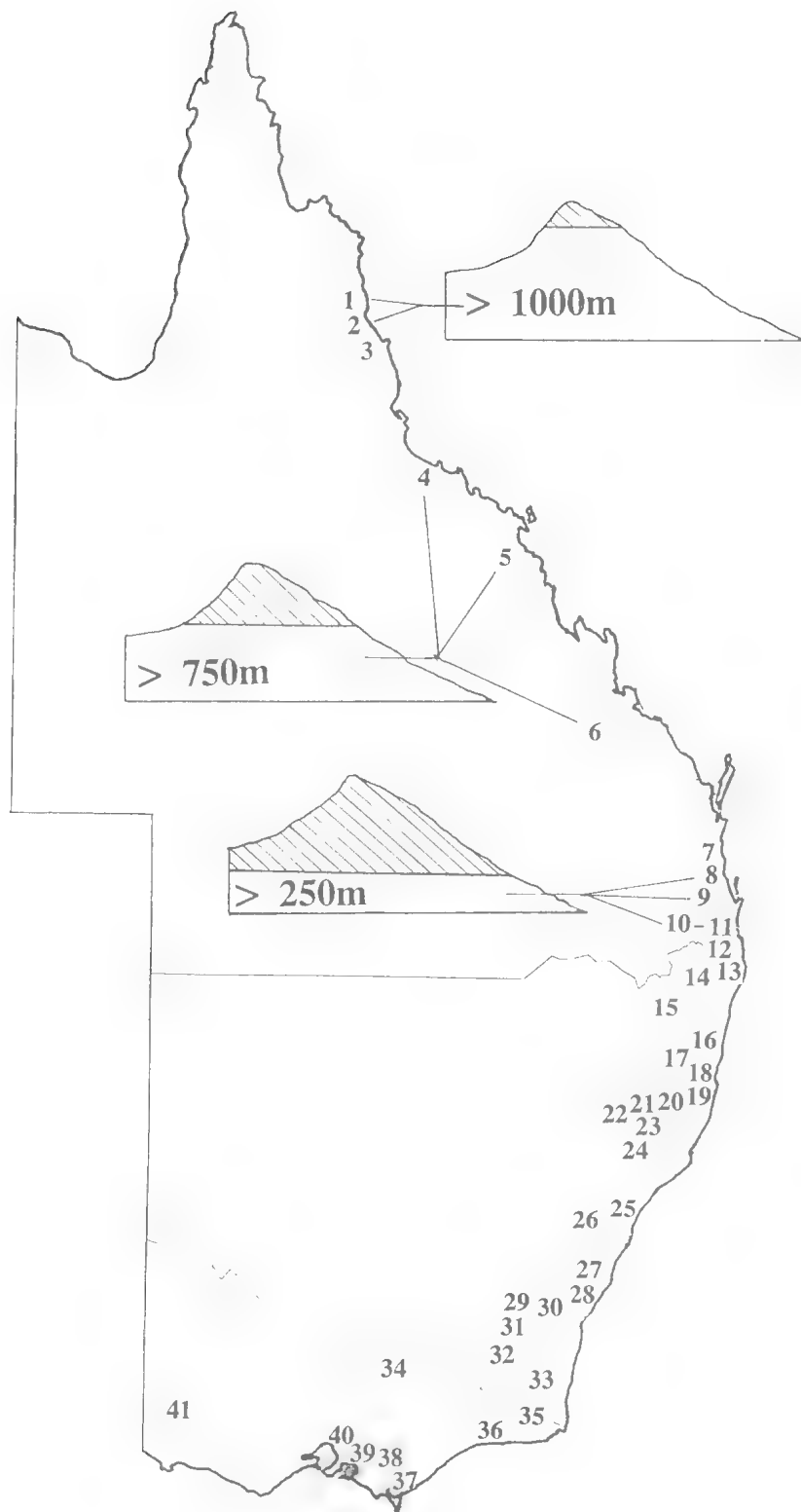
Although temnocephalans are common on many Australian freshwater crustaceans, most are undescribed. Fourteen species in 3 genera have been recognised from mainland crabs and shrimps (Cannon, 1993a) and 11 proposed new species have been found in the branchial chamber of mainland freshwater crayfish (Cannon &

Table 1 a-c. Symbionts recorded from 3 species of cultured Australian crayfish

\* = from laboratory reared crayfish only

(a) REDCLAW <i>Cherax quadricarinatus</i>	
SYMBIONT	REFERENCE
BACTERIA	
<i>Mycobacterium chelonae</i>	Anderson (1990)
<i>Pseudomonas</i> sp.	Pearce (1990)
<i>Vibrio cholera</i>	Eaves & Keiterer (1990, unpublished) in Anderson (1990)
FUNGI	
fungi sp.	Herbert (1987)
? <i>Achlya</i> sp.	Herbert (1987)
<i>Achlya</i> sp.	Pearce (1990)
? <i>Allomyces</i> sp.	Pearce (1990)
<i>Saprolegnia</i> sp.	Herbert (1987)
<i>Lagenidium</i> sp.	Sammy (1989)
oomycetes sp.	Herbert (1987)
<i>Phythium</i> sp.	Sammy (1989)
<i>Psorospermium</i> sp.	Herbert (1987)
<i>Saprolegnia</i> sp.	Sammy (1989)
MICROSPORA	
<i>Thelohania</i> sp.	Herbert (1988)
CILIOPHORA	
<i>Lagenophrys darwini</i>	Kane (1965)
<i>Lagenophrys lawrti</i>	Kane (1965)
<i>Lagenophrys</i> sp.	Herbert (1987)
<i>Vavraia</i> sp.	Langdon (1989)
<i>Zoothamnium</i> sp.	Herbert (1987)
<i>Epistylis</i> sp.	Herbert (1987)
* <i>Vorticella</i> sp.	Herbert (1987)
PLATYHELMINTHES	
<i>Craspedella</i> sp. nov.	Cannon & Sewell (unpublished)
<i>Decudidymus gulosus</i>	Cannon (1991)
<i>Diceratocephala boschmai</i>	Cannon (1991)
<i>Didymorchis</i> sp.	Cannon & Sewell (unpublished)
<i>Notodactylus handschuni</i>	Cannon (1991)
<i>Temnocephala rouxii</i>	Cannon (1991)
NEMATODA	
nematoda sp.	Herbert (1987)
ANNELIDA	
<i>Stratiodrilus novaehollandiae</i>	Jones (1992)
ARACHNIDA	
mite sp.	Cannon & Sewell (unpublished)

Fig 1. Distribution in eastern Australia of named species of *Euastacus* (after Morgan 1986, 1988, 1989; Merrick, 1993) and *Euastacus* spp. (Morgan, in press) and showing elevations above which they are found in Queensland: (1 *E. robertsi*, 2 *E. fleckeri*, 3 *E. balanensis*, 4 *E. bindal*, 5 *E. eungella*, 6 *E. monteithorum*, 7 *E. urospinus*, 8 *E. hystricosus*, 9 *E. setosus*, 10 *E. jagara*, 11 *E. madae*, 12 *E. sulcatus*, 13 *E. valentulus*, 14 *E. sp.*, 15 *E. suttoni*, 16 *E. neohirsutus*, 17 *E. simplex*, 18 *E. sp.*, 19 *E. hirsutus*, 20 *E. sp.*, 21 *E. sp.*, 22 *E. sp.*, 23 *E. polysetosus*, 24 *E. reductus*, 25 *E. spinifer*, 26 *E. australiensis*, 27 *E. sp.*, 28 *E. sp.*, 29 *E. crassus*, 30 *E. sp.*, 31 *E. claytoni*, 32 *E. sp.*, 33 *E. brachythorax*, 34 *E. ornatus*, 35 *E. bidawalus*, 36 *E. diversus*, 37 *E. neodiversus*, 38 *E. kershawi*, 39 *E. yarraensis*, 40 *E. woiwuru*, 41 *E. hispinus*).





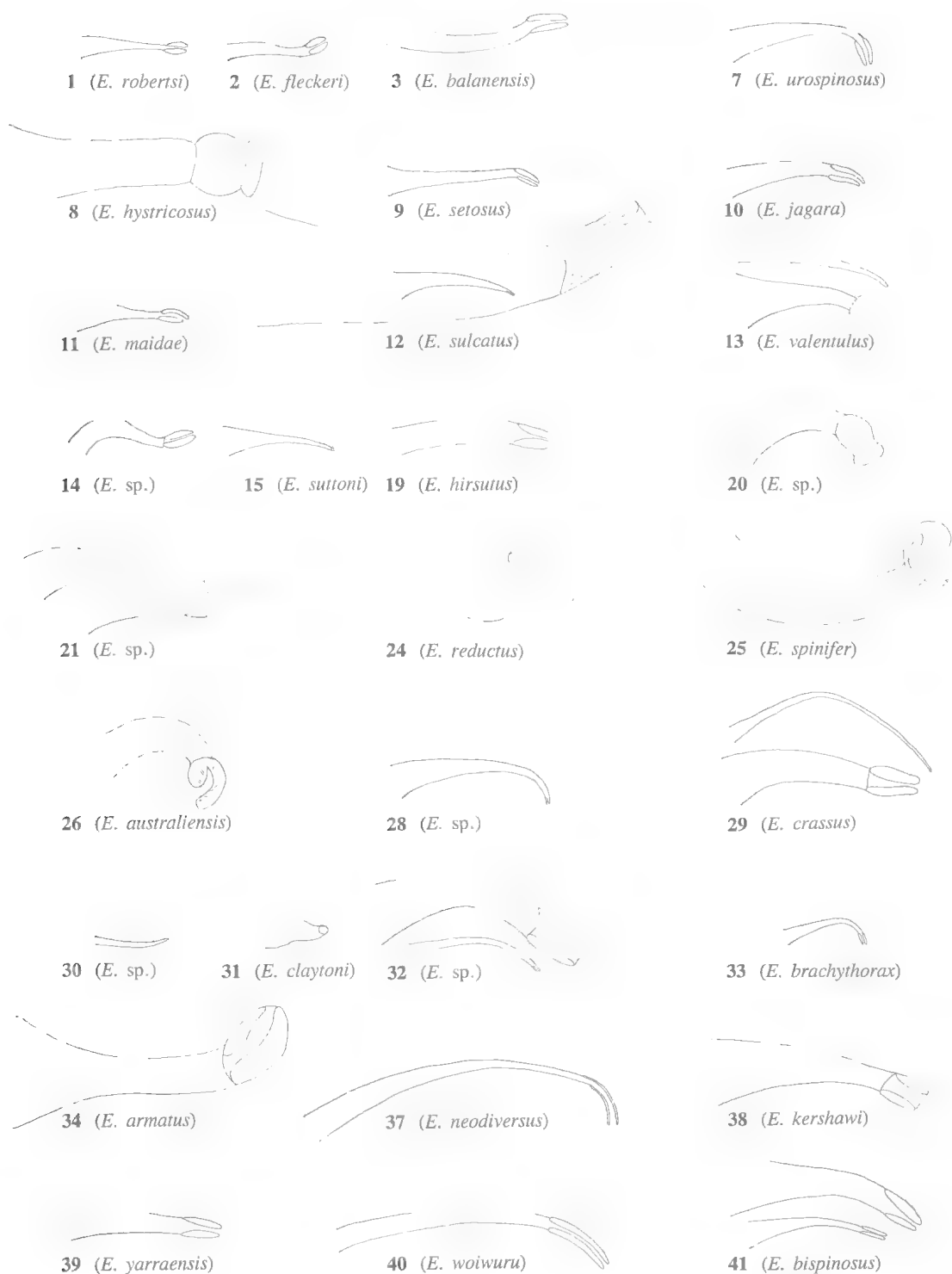


Fig 2. Male organs of temnocephalans taken from *Euastacus* spp. (locality from Fig. 1 and name in parentheses).

Table 1 b, c. (continued) Symbionts recorded from 3 species of cultured Australian crayfish

\* = from laboratory reared crayfish only

(b) YABBIE <i>Cherax destructor</i>	
SYMBIONT	REFERENCE
BACTERIA	
<i>Pseudomonas</i> sp.	Copland (1981)
FUNGI	
<i>Saprolegnia</i> sp.	Merrick & Lambert (1991)
MICROSPORA	
microsporidia sp.	Langdon (1989)
<i>Thelohania</i> sp.	Carstairs (1979)
CILIOPHORA	
<i>Epistylis</i> sp.	Herbert (1987)
<i>Lagenophrys communis</i>	Kane (1965)
<i>Lagenophrys latispinosa</i>	Kane (1965)
<i>Lagenophrys lingulata</i>	Kane (1965)
<i>Lagenophrys ocellata</i>	Kane (1965)
<i>Lagenophrys seticola</i>	Kane (1965)
<i>Lagenophrys spinosa</i>	Kane (1965)
<i>Lagenophrys willisi</i>	Kane (1965)
<i>Pyxicola jacobii</i>	Kane (1964)
<i>Pyxicola bicalceata</i>	Kane (1964)
rotifer sp.	Kane (1964)
PLATYHELMINTHES	
cestoda sp.	Gardner (unpublished) in Mills (1983)
<i>Craspedella spenceri</i>	Kane (1964)
<i>Diceratocephala</i> sp.	Kane (1964)
<i>Didymorchis</i> sp.	Rohde (1987)
<i>Temnocephala dendyi</i>	Williams (1978)
<i>Temnocephala minor</i>	Williams (1978)
NEMATODA	
nematoda sp.	Mills (1983)
ARACHNIDA	
mite sp.	Kane (1964)
CRUSTACEA	
<i>Notocyther mirrantia</i>	Hart & Hart (1967)
<i>Notocyther syssitos</i>	Hart & Hart (1967)
ostracod sp.	Mills (1989)

(c) MARRON <i>Cherax tenuimanus</i>	
SYMBIONT	REFERENCE
FUNGI	
fungi sp.	Evans (1986)
<i>Saprolegnia</i> spp.	Pass & Morrissey (1984, unpublished) in Glazebrook, Owens & Campbell (1985)
MICROSPORA	
microsporidia sp.	Langdon (1990)
<i>Thelohania</i> sp.	Pearce (1990)
CILIOPHORA	
<i>Cothurnia</i> sp.	Evans (1986)
<i>Epistylis</i> sp.	Herbert (1987)
<i>Lagenophrys deserti</i>	Kane (1965)
<i>Vavraia</i> sp.	Langdon (1989)
<i>Zoothamnium</i> sp.	Herbert (1987)
PLATYHELMINTHES	
<i>Temnocephala</i> sp.	Cannon & Sewell (unpublished)
<i>Temnocephala minor</i>	Cannon & Sewell (unpublished)
NEMATODA	
nematoda sp.	Evans (1986)

observations). The Tasmanian temnocephalan fauna was described by Hickman (1967).

## BIODIVERSITY AND CONSERVATION

Cultured crayfish are well studied and their recorded symbionts are diverse. At present few symbionts are known from *Euastacus*, but our temnocephalan data suggest that a similar increase in the number of known symbionts would occur should these hosts be regarded as important as those we eat. The biodiversity of symbionts probably will exceed that of their hosts. Rohde (1976) estimated that whereas the fish fauna of the Great Barrier Reef may approach 2000 species, the parasite fauna could be as high as 20,000 species in those fish. Similarly, Price (1980), who considered plants as hosts, found that 92% of all animal species are parasites. Clearly, *conserving biodiversity means conserving symbionts*.

Conserving symbionts has important ecological consequences. Freeland (1993) demonstrated the ecological significance of parasites which can help sustain host populations by dampening their oscillations to reduce the probability of local host extinctions. Also, Horwitz (1990b) warned introductions of foreign crayfish and associated symbionts may lead to loss of unique symbiont fauna. This view has been supported by Cannon (1993b) who reported the native temnocephalan fauna of

Sewell, in prep.). We have found large, brown pigmented temnocephalans with 5 tentacles inhabit the surface of most *Euastacus* spp. Although only one species (*Temnocephala fasciata*) has been described (Haswell, 1893), we have found that there is considerable diversity in the shape and/or size of the sclerotic male copulatory organs (the only hard parts of these worms) on *Euastacus* from Cape York, Queensland to the Grampian Range on the border of Victoria and South Australia (Fig. 2). This we believe is strong evidence that there are many undescribed species of temnocephalans on these crayfish.

Smaller non-pigmented worms with 6 tentacles occur on many *Euastacus*: these also await description. In addition, there are other worms from *Cherax* spp. and *Engaeus* spp. (unpublished

marron, *Cherax tenuimanus*, has largely been displaced in aquaculture by the pest *Temnocephala minor* which has apparently been introduced via the translocation of its natural hosts *Cherax albidus* Clark, 1936 and/or *C. destructor* into aquaculture with marron.

Thus, symbionts make a major contribution to biodiversity, and their conservation has important ecological implications. We must recognise that even parasitism, as a form of symbiosis, can be beneficial in maintaining biodiversity. Our own attitudes and perceptions have been strongly influenced by observations made during the extensive fieldwork required for this study. We travelled a total of more than 15,000km by road through 5 Australian states in search of *Euastacus* and other freshwater crayfish hosts. Our *modus operandi* was to seek crayfish species in localities where, according to Museum collection records, they had previously been collected. We repeatedly found documented crayfish habitat to be eutrophic, muddy wallows caused by stock having degraded stream banks, destroying riparian vegetation and thereby eliminating habitat and crayfish. Merriek (1993) reported these and related factors as the main threat to the conservation of *Euastacus* in New South Wales. Not only animals are under threat from pastoral practices. Recently, Cheal (1993) concluded from a study of grazing stock in Victoria that 'there was almost total lack of regeneration of trees and shrubs throughout the grazed areas, and their extinction is inevitable if stock grazing is maintained'. Clearly, if we wish to maintain biodiversity in Australia we must espouse a more flexible attitude to primary industries based upon sustainable natural resources. Encouraging evidence exists that outdated practices and attitudes are changing. The Landcare program now boasts 25% of the farming community as supporters (ABC programme - Landcare, 5th Sept 1993).

Essentially, we believe there is the need to limit human population growth. In Australia, the debate on population has been hijacked by historians, sociologists, economists and other 'authorities' (see Ruthven, 1992), who appear ignorant of the biological imperative that a species will exploit its resources and grow until limited, i.e. from disease, conflict or from lack of space, shelter, food or water. The quality of our lives, the nature of our society and our economic structure all ultimately rest on the figure we set for our desired population. In such a dry continent we fear we are perilously close to that limit.

This account has centred upon crayfish of the genus *Euastacus* and their unique position as prominent invertebrate hosts/habitats for a wide diversity of symbiotic invertebrates. As such, these large, often strikingly handsome crayfish could act as 'flagship species' or 'ambassadors' to focus our attention on the need to preserve invertebrate species and their habitat. Indeed, Horwitz (1990b) says 'the freshwater crayfish of Australia rank as one of, if not, the most important groups on which to base a discussion of the conservation of freshwater crustaceans'. We would like to add - 'and of invertebrates and biodiversity itself'.

#### ACKNOWLEDGMENTS

The support of the Queensland Museum is gratefully acknowledged. We thank officers of the National Parks and Forestry, from Queensland, New South Wales and Victoria for assistance with the collection of crayfish. We also thank Dr Sylvie Pichelin whose comments improved an earlier draft of this manuscript. This work was funded by an Australian Biological Resources study grant 88/5909 awarded to LRGC.

#### LITERATURE CITED

- ANDERSON, I. 1990. Diseases - what type and how to prevent them, Australian Fisheries Redclaw Aquaculture Special Edition 49: 32-34.
- BENEDEN, J.P. van., 1876. 'Animal parasites and messmates'. (H.S.King: London) (International Scientific Series XX) 274 pp.
- CANNON, L.R.G. 1991. Temnocephalan symbionts of the freshwater crayfish *Cherax quadricarinatus* from northern Australia. *Hydrobiologia* 227: 341-347.
- 1993a. New temnocephalans (Platyhelminthes): ectosymbionts of freshwater crabs and shrimps. *Memoirs of the Queensland Museum* 33: 17-40.
- 1993b. Of temnocephalans, translocations and triumphs: the rediscovery of *Temnocephala chaeropsis* Heit. 1925, a worm nobody knew was lost. Abstract No. 53 in the Programme and Abstracts of papers presented at the 7th International Symposium on the biology of the Turbellaria. 17-22nd June 1993 in Åbo, Turku, Finland.
- CANNON, L.R.G. & JENNINGS, J.B. 1987. Occurrence and nutritional relationships of four ectosymbionts of the freshwater crayfishes *Cherax dispar* Riek and *Cherax punctatus* Clark (Crustacea: Decapoda) in Queensland. *Australian Journal of Marine and Freshwater Research* 38: 419-427.

- CARSTAIRS, I.L. 1979. Report of microsporidial infestation of the freshwater crayfish, *Cherax destructor*. *Comparative Biochemistry and Physiology* 64(b): 235-238.
- CHEAL, D.C. 1993. Effects of stock grazing on the plants of semi-arid woodlands and grasslands. *Proceedings of the Royal Society of Victoria* 105: 57-65.
- COPLAND, J.W. 1981. Diseases of freshwater crayfish and fish. Pp. 84-96. In Carroll, P.N. (ed.) 'A Yabbie Pot-Pourri'. (Hawkesbury Agricultural College, Richmond.)
- EVANS, L. 1986. Diseases and parasites. Summary of a paper delivered to the annual General Meeting of the Marron Growers Association 1986. *Austasia Aquaculture* 1(5): 4-6.
- FREELAND, W.J. 1993. To parasites with love! Programme and abstracts of the Towards Biodiversity and Conservation Conference. Queensland Museum 12-15th July 1993.
- GLAZE BROOK, J.S., OWENS, L. & CAMPBELL, R.S.F. 1985. Diseases of Crustacea relevant to Australia. In Humphrey, J.D. & Langdon, J.S. (eds) 'Proceedings of the workshop on diseases of Australian fish and shellfish'. Australian Fish Health Reference Laboratory, regional Veterinary Laboratory Benella, May 27-30, 1985.
- HART, C.W. & CLARK, J. 1987. An interdisciplinary bibliography of freshwater crayfishes (Astacoidea and Parastacoidea) from Aristotle through 1985. *Smithsonian Contributions to Zoology* no. 455. (Smithsonian Institution Press: Washington, D.C.)
- HART, C.W. & HART, D.G. 1967. The entocytherid ostracods in Australia. *Proceedings of the Academy of Natural Sciences Philadelphia* 119: 1-51.
- HASWELL, W.A. 1893. A monograph of the temnocephaleae. *Proceedings of the Linnean Society of New South Wales (Macleay Memorial Volume)* pp. 94-152.
- HERBERT, B. 1987. Notes on diseases and epibionts of *Cherax quadricarinatus* and *C. tenuimanus* (Decapoda: Parastacidae). *Aquaculture* 64: 165-173.
- HERBERT, B.W. 1988. Infection of *Cherax quadricarinatus* Decapoda: Parastacidae by the microsporidium *Thelohania* sp. (Microsporida: Nosematidae). *Journal of Fish Diseases* 11: 301-308.
- HICKMAN, V.V. 1967. Tasmanian Temnocephalidea. *Papers and Proceedings of the Royal Society of Tasmania* 101: 227-250.
- HORWITZ, P. 1990a. The translocation of freshwater crayfish in Australia: potential impact, the need for control and global relevance. *Biological Conservation* 54: 291-305.
- 1990b. The conservation status of Australian freshwater crustacea with a provisional list of threatened species, habitats and potentially threatening processes. Australian National Parks and Wildlife Service Report Series No. 14, 121 pages.
- JENNINGS, J.B. 1988. Nutrition and respiration in symbiotic Turbellaria. In Ax, P., Ehlers, U. & Sopott-Ehlers, B. 'Free-living and Symbiotic Platyhelminthes'. (Gustav Fischer: Stuttgart). pp. 1-13.
- JONES, T.C. 1992. On the biology of a temnocephalan ectosymbiont *Diceratocephala boschmai* on the Queensland redclaw crayfish *Cherax quadricarinatus*. (Unpublished PhD Thesis, University of Queensland.)
- KANE, J.R. 1964. The Australian freshwater Malacostraca and their epizotic fauna. (Unpublished MSc. Thesis, University of Melbourne.)
1965. The genus *Lagenophrys* Stein, 1852 (Ciliata, Peritricha) on Australasian Parastacidae. *Journal of Protozoology* 12: 109-122.
- LANGDON J.S. 1989. Marron: Microsporidial Disease. Control and Therapy Series 149: 138-138.
1990. Microsporidiosis in the Marron *Cherax tenuimanus*. Summary of a paper delivered to the Australian Society for Fish Biology in 1989. *Austasia Aquaculture* 4: 19.
- MERRICK, J.R. 1993. 'Freshwater crayfishes of New South Wales'. (Linnean Society of New South Wales: Southwood Press, Marrickville). 127 pp.
- MERRICK, J.R. & LAMBERT, C.N. 1991. 'The Yabby, Marron and Redclaw. Production and Marketing'. (J.R. Merrick Publications: Sydney)
- MILLS, B.J. 1983. A review of the diseases of freshwater crayfish, with particular reference to the yabby, *Cherax destructor*. Fisheries Research Paper 9: 1-18. Department of Fisheries, South Australia
- MILLS, B.J. 1989. Australian Freshwater Crayfish. Handbook of Aquaculture. (Freshwater-Crayfish Aquaculture Research and Management: Lymington). 116pp.
- MORGAN, G.J. 1986. Freshwater crayfish of the genus *Euastacus* Clark (Decapoda: Parastacidae) from Victoria. *Memoirs of the Museum of Victoria* 47: 1-57.
1988. Freshwater crayfish of the genus *Euastacus* Clark (Decapoda: Parastacidae) from Queensland. *Memoirs of the Museum of Victoria* 49: 1-49.
1989. Two new species of the freshwater crayfish *Euastacus* Clark (Decapoda: Parastacidae) from isolated high country of Queensland. *Memoirs of the Queensland Museum* 27: 555-562.
- in press. Freshwater crayfish of the genus *Euastacus* Clark (Decapoda: Parastacidae) from New South Wales, with a key to all species of the genus. *Records of the Australian Museum*.
- PEARCE, M.C. 1990. Redclaw diseases. Pp. 29-31. In Shelley C.C. & Pearce M.C. (eds) 'Proceedings of the Seminar Farming the Redclaw Freshwater Crayfish'. (Northern Territory Department of Primary Industry and Fisheries: Darwin).

- PRICE, P.W. 1980. 'Evolutionary biology of parasites'. (Princeton University Press: Princeton).
- ROHDE, K. 1976. Species diversity of parasites on the Great Barrier Reef. *Zeitschrift für Parasitenkunde* 50: 93-94.
1987. Ultrastructural studies of epidermis, sense receptors and sperm of *Craspedella* sp. and *Didymorchis* sp. (Platyhelminthes, Rhabdocoela). *Zoologica Scripta* 16: 289-295.
- RUTHVEN, P. 1992. Ruthven in 'Viewpoint' by C. Ashton. p.13. In 'The Australian Way' (Australian Airlines/POL Concepts: Redfern, Jan, 1992).
- SAMMY N. 1989. Breeding biology of *Cherax quadricarinatus* in the Northern Territory. *Austasia Aquaculture* 3: 7: p. 5.
- SCHMIDT, G.D. & ROBERTS, L.S. 1989. 'Foundations of Parasitology'. (Times Mirror/Mosby College Publishing: St. Louis).
- WILLIAMS, J.B. 1978. Studies on the epidermis of *Temnocephala*. III. Scanning electron microscope study of the epidermal surface of *Temnocephala dendyi*. *Australian Journal of Zoology* 26: 217-224.



# IS THE PUBLIC REALLY INTERESTED IN INVERTEBRATES? WHAT THE QUEENSLAND MUSEUM REFERENCE CENTRE ENQUIRIES FROM 1986-1993 TELL US

GREGORY V. CZECHURA

Czechura, G.V. 1994 06 30: Is the public really interested in invertebrates? What the Queensland Museum Reference Centre enquiries from 1986-1993 tell us. *Memoirs of the Queensland Museum* 36(1): 41-46. Brisbane. ISSN 0079-8835.

Many of the successes of wildlife conservation can be attributed to public interest in, and sympathy for, the animals that are the subjects of such programs. Traditionally, most attention has focused on vertebrates, especially birds and mammals. There is an increasing need to extend public sympathy and interest to invertebrates. An analysis of natural history enquiries received at the Queensland Museum Reference Centre was used to determine present levels of public interest in invertebrates and to understand why people were interested. Vertebrates dominated enquiries but the levels of interest in spiders and insects were similar to those for birds and mammals. Interest in invertebrates was usually highly specific: taxa that were perceived to be dangerous or spectacular in appearance attracted most attention. In conclusion, I summarise the problems for marketing invertebrates and suggest solutions. I stress that there has to be a concerted commitment to the production of readily available information. □ *Museum, education, invertebrates, information, popularity, enquiries, marketing, folk, biodiversity, conservation, Queensland, Australia.*

Gregory V. Czechura, Queensland Museum, PO Box 3300, South Brisbane, Queensland 4101, Australia; 1 September 1993.

Biodiversity has become a major conservation issue and one that is increasingly focusing attention on plant and animal groups that have received little or no attention in the past. Traditionally, these issues have highlighted flagship taxa — especially rare or threatened species — that were usually vertebrates, and mostly birds or mammals. A typical example is the Algerian Nuthatch (*Sitta ledanti*). The discovery in 1975 of this small bird was used to promote a successful campaign for the preservation of the oak-cedar-fir forest remnant of Djebel Babor, Algeria (Diamond et al., 1989).

Even though invertebrates are receiving more attention in conservation, there is still a strong bias towards the higher vertebrates. In part, this is a matter of education. For example, many textbooks describe mammals as the dominant animals on the earth today (e.g. DeBlase & Martin, 1974; also see Plowman, 1994). Further, invertebrates lack the widespread, emotional appeal of vertebrates. For example, the shooting of large numbers of migrating birds over Malta created widespread revulsion and international protest (Fenech, 1992; Taylor, 1992). In contrast, the indiscriminate destruction of large numbers of insects as a consequence of mosquito control programs in the tropics raises little response. In-

deed, such slaughter can be popularly regarded as benign, if not beneficial. If concern about mosquito control is expressed, it is usually about the effects of pesticides on the birds, frogs and fish that share the wetlands with the insects.

Public support is a vital part of successful wildlife conservation and is expressed through political canvassing, financial support, practical assistance, access to private lands and provision of specimens. Given that invertebrates will be receiving greater attention from conservationists, three questions arise about public acceptance of this change in focus.

Firstly, are the public interested in invertebrates and what aspects interest them? Secondly, what strategies are likely to prove to be successful in marketing invertebrates? And finally, is the popularity of vertebrates a problem for marketing invertebrates?

The Reference Centre of the Queensland Museum has maintained records of enquiries from 1986 to the present. These records are examined to seek answers to these questions.

## THE REFERENCE CENTRE

The Queensland Museum Reference Centre acts as an interface between the general public

TABLE 1. Reference Centre enquiries: totals for subject areas as represented by the museum's curatorial sections.

Subject	% Total enquiries
Reptiles	28.7
Arachnids	15.1
Insects	10.1
Birds	9.9
Mammals	7.1
General	7.2
Amphibia	6.6
Palaeontology/Geology	4.0
History/Technology	3.3
Fish	1.7
Anthropology/Archeology	1.7
Molluscs	1.2
Other Invertebrates	1.1
Crustacea	0.8
Preparation	0.7
Maritime Archeology	0.4
Conservation	0.2

and the museum's curatorial sections. Operation and design philosophy of the centre are based on similar centres operated at the Smithsonian Institution (Madden, 1978), University of Papua New Guinea (Lambley & Frodin, 1987) and the South Australian Museum. The Centre has been in operation since October 1986 when the Queensland Museum moved to its present site in South Brisbane. Scoullar (1989) has reported on broad aspects of the Centre's operations while Czechura (1987, 1993) and Scoullar (1993) have reported information on specific displays and information-gathering projects.

The prime function of the Reference Centre is to screen incoming enquiries and be the interface between the public and the rest of the institution. Enquiries can be made in writing, by telephone or through direct contact. Telephone enquiries are received via the Centre's switchboard or referred from elsewhere in the Queensland Cultural Centre complex. Two permanent members of staff operate the Centre. They are assisted by a receptionist and a varying number of casual staff (Interpretation Officers).

#### REFERENCE CENTRE ENQUIRIES

A total of 125,314 face-to-face, telephone and written public enquiries were recorded by staff of

the Reference Centre from October 1986 to 30 June 1993. These figures actually under-represent the numbers of enquiries received because, in peak periods with constant demand, there may be not enough time to do the physical act of recording. As an indication of the workload, for the period August 1992 to June 1993, at the telephone switchboard alone, 28,849 telephone enquiries were received. Of these, 17,563 (60.9%) were attended to by staff of the Reference Centre. In addition, the staff responded to enquiries at the counter, letters and direct calls to their telephone extensions. These totals also indicate that the Centre is functioning as an effective screen and interface between the public and other museum staff, thus considerably reducing the latter's workloads and enhancing their productivity.

Tables 1-6 are summaries of the enquiries in terms of Queensland Museum's curatorial sections and by invertebrate groups (Tables 1-6).

#### DISCUSSION

The first breakdown (Table 1) shows that the Queensland Museum is actively sought by public as an information resource for a variety of topics. The greatest demand is in the area of natural history and enquiries for identification of, and information about, animals account for 82.5% of the total. Within natural history, ver-

Subject	% Total enquiries
General	7.4
Araneomorphs	65.6
<i>Redbacks</i>	28.9
<i>Huntsmen</i>	16.1
<i>Large Orb-weavers</i>	14.8
<i>White-tailed Spider</i>	11.7
<i>Dome-web Spider</i>	6.4
<i>Wolf Spiders</i>	6.0
<i>Black House Spider</i>	3.7
Mygalomorphs	17.0
<i>Funnel-webs</i>	20.1
<i>Tarantulas</i>	18.2
<i>Whistling Spiders</i>	16.9
Centipedes/Millipedes	3.5
Mites/Ticks	3.0
Scorpions	3.5

TABLE 2. Arachnid enquiries: totals for dominant taxa. Italics indicate totals within these groups

TABLE 3. Insect enquiries: totals for dominant taxonomic groups.

Subject	% Total enquiries
General	20.8
Blattodea	1.1
Coloptera	4.7
Diptera	5.5
Hemiptera	6.6
Hymenoptera	19.9
Isoptera	3.9
Lepidoptera	25.2
Mantodea	1.4

TABLE 4. Crustacean enquiries: totals for dominant taxonomic groups.

Subject	% Total enquiries
General	2.3
Amphipods	12.5
Crabs	35.0
Freshwater Crayfish	20.2
Isopods	30.0

tebrates are the most popular group of animals (54.2% of total) compared to invertebrates (28.3% of total). Nevertheless, two invertebrate groups, spiders and insects respectively, rate as the second and third most popular topics.

It may also be significant that the top seven popular animal groups are terrestrial and characterised by high diversities and densities of species in southern Queensland (Ingram & Raven, 1991), from where most enquiries originate. This suggests people are in close contact with animals and are seeking information on those species that successfully share their increasingly urbanised environment.

For invertebrates, what motivates people to approach the Queensland Museum for information about, or identification of, a specimen in the first place? This question can be answered by examining the data from enquiries for the two dominant, invertebrate, enquiry groups (Tables 2, 3): spiders and insects; and from my personal experience with these enquiries.

For spiders, there appear to be six categories of motives (which can overlap) for contacting the museum for information. First, there is concern about, which may or may not be justified, the presence of dangerous or venomous species in dwellings and workplaces following an en-

counter with a suspect animal. Enquirers are usually worried about being bitten, especially where children are involved. The spiders responsible for the anxiety are usually described by the caller as 'large', 'hairy', 'aggressive', 'black' and other masculine metaphors. Not only do obvious physical features attract people's attention, personal (or shared) interpretations of common names (often wrong) also contribute to apprehension in an encounter (this happens with snake names, too). For example, fear of white-tailed spiders (*Lampona* spp.) results in queries about any spider that has white markings on its abdomen. Overall, the spiders that are commonly responsible for anxious enquirers include: all mygalomorph spiders, huntsman spiders (Heteropodidae), Garden Orb-weaving Spiders (*Eriophora transmarina*), daddy long-legs (Pholcidae) and all species known to be medically significant.

TABLE 5. Mollusc enquiries: totals for dominant ecological and taxonomic groups. Italics indicate totals within these subject areas.

Subject	% Total enquiries
Terrestrial Molluscs	27.1
<i>Red Triangle Slug</i>	4.3
<i>Hedleyella</i> spp.	18.8
Marine Molluscs	39.0
<i>Cones</i>	18.7
<i>Cowries</i>	17.7
<i>Other Gastropods</i>	9.3
<i>Bivalves</i>	2.3
<i>Nudibranchs</i>	4.2
<i>Cephalopods</i>	47.8
<i>Blue-ringed Octopus</i>	64.0

TABLE 6. Reference Centre other invertebrate enquiries: totals for dominant taxonomic groups. Italics indicate totals within these subject areas.

Subject	% Total enquiries
General	4.5
Annelids	18.2
Cnidaria	34.1
<i>box jellyfish</i>	40.0
Echinoderms	9.1
Nemertodes	27.3
<i>gordian worms</i>	58.3
Platyhelminths	6.8

The second and third categories of motivation for enquiries also result from personal encounters with live spiders but, here, their enquiries are motivated by curiosity rather than fear. The second is concerned with large spectacular animals, such as Dome-web Spiders (*Cyrtophora moluccensis*), golden orb-weaving spiders (*Nephila* spp.), whistling spiders (*Selenocosmia* spp.) and any spider thought to be a 'tarantula'. The third is concerned with animals that can be deemed unusual in their physical appearance (e.g. triangular spiders (*Arkys* spp.), six-spined spiders (*Gasteracantha* spp.), various flower spiders (Thomisidae) and Two-spined Spiders (*Poecilopachys australasiae*).

The fourth category includes any enquiries stimulated by reading, discussion and school projects. These are typically specific and are not generated through direct contact with animals. These sorts of enquiries often arrive at definite times of the year and in large numbers, especially where schools are involved. The subjects of the enquiries are repetitive and include arachnids such as 'tarantulas', or threatened or dangerous spiders.

The fifth category comprises enquiries generated by responses to stories in the media. The species featured are usually known to be dangerous, or perceived to be so, because they have been treated in a sensational manner by the media — often under the head-line of 'BACK-YARD KILLERS' or similar screamers. Most enquiries of this type are superficial and require counselling skills (caring and understanding for a frightened fellow human) more than knowledge of spiders. The spiders involved are usually Redbacks (*Latrodectus hasseltii*) and funnel-web spiders (*Hadronyche* spp.) because they are potentially dangerous and excellent fodder for sensationalist media. Like the previous category, these enquiries do not necessarily involve direct contact with the animals. However, a media report may have motivated a search-and-discovery of suspect animals ('I saw the story on TV and then I found this spider...').

The final category involves people seeking reassurance, either through confirmation or denial, of popular myths (as such, these enquiries resemble the responses arising from sensational media reports). Myths may be recurrent or idiosyncratic. An example of a recurrent myth is the widespread belief that daddy long-legs possess an extremely toxic venom that they are unable to use because their fangs are too short.

Interest in insects is broadly similar to that of

spiders but there are some clear differences. For example, popular myths appear to be much less significant. High species diversity and seasonal patterns of abundance seem to preclude any one species from dominating public attention. The medically significant category is not as important in insects simply because there are no equivalents to funnel-webs or Redbacks, but there is concern about pest species damaging possessions and livelihood. Enquiries involving medically significant insects relate to stinging or biting insects such as assassin bugs, bees, wasps and mosquitoes. Common subjects for pests are termites and those insects — or their larvae — responsible for destroying garden plants.

Curiosity ensures that interest is maintained in large, spectacular species (Giant Wood Moth *Xyleutes cinereus*), unusual and/or bizarre species (e.g. gall-forming eriococcid scale-insects) and species that have spectacular irruptions or migrations (e.g. cutworm moths *Agrotis* spp.; 'granny's cloak moth' *Speiredonia* spp. or *Dasypodia* spp.; and Caper White Butterflies *Anaphaeis java*). Enquiries about irruptive species can also include concern about the possibility that the insects are pests that could cause damage.

Media-generated interest is also a feature of insect enquiries. For example, the increasing attention being given to feral european wasps (*Vespula* spp.) in southern Australia is presently responsible for a heightened awareness of all species of wasps.

Special interest in insects also exists. Butterflies, cicadas, dragonflies and some groups of beetles have traditionally attracted amateur naturalists (and continue to do so). Enquiries about these four insect groups can be quite similar to those asked about birds: details of natural history or classification are often sought. The identifications required are more technical and can involve difficult-to-identify, superficially similar species or new locality sightings. These enquirers can be very knowledgeable with more than a passing interest in the animals.

## CONCLUSION

A general feature of all Reference Centre natural history enquiries is that many of them are repetitively concerned with a relatively narrow core of subjects. With invertebrates, the animals that form this core can be described as mainly medically significant, large or spectacular. Typical examples are: Gordian worms (Nematomor-

pha), Red-triangle Slugs (*Triboniophorus graefei*), Blue-ringed Octopus (*Hapalochlaena* spp.), Redbacks, huntsman spiders and funnel-web spiders. However, there is little public interest in invertebrates outside this core.

What are the implications for biodiversity? Firstly, there needs to be an intense and wider commitment to the provision and management of information about invertebrates. Popular interest has to be encouraged and massaged. The present interest in the core invertebrate groups has to be transformed into a larger interest: the core's popularity has to be made to redound for other invertebrates. At present, such effort are dogged by a lack of available information about the groups that are not popular (Shield & Harrison, 1994). This has to be remedied.

Secondly, it has to be remedied fast. Extinction rates are apparently much higher in invertebrates (e.g. non-marine molluscs; Ponder, 1994) and only popular opinion, which still has to be created, will save them. There has to be a concerted commitment to the production of readily available information.

The following are five immediate issues that require careful consideration in developing invertebrate marketing strategies:

1. Not all taxa will inspire general interest. And how can existing interest in core groups be used to popularize other species.
2. There is an overall lack of available information. A concerted approach is needed using (and in creating) field guides, non-technical references, displays, exhibitions and media articles. There is also a need to target regional or perceptual groups of animals rather than standard taxonomic approaches, e.g. guides to house spiders rather than spiders of Queensland.
3. The lack of common names needs to be addressed.
4. Pejorative images of invertebrates need to be fought, e.g. not all Diptera are disease vectors.
5. In a straitened economy, wider cooperation and sharing of resources will be necessary to meet aims. In this, notable successes have been achieved with exhibitions both locally ('Insects — Friend & Foe', Queensland Museum) and nationally ('Gargantuans from the Garden', Australian Museum) involving many different contributors.

Finally, is there a problem with the continuing, intense popularity of vertebrates in natural history? In museums, there is. Rare resources are used in maintaining curatorial sections for very, small groups of animals — vertebrates — because of their popularity. For example, in the Queensland Museum there are five sections for

vertebrates but only seven for invertebrates, even though invertebrates comprise nearly 95% of the animal kingdom. Compared to invertebrates, the need for taxonomic research in Australian vertebrates is diminishing — in some groups it is not needed at all. Unfortunately attempts to restructure research programs to recognise this reality have often led to extra-institutional resistance and criticism.

However, the point that is often missed in the resultant debates about restructuring is that 'public interest in vertebrates' and 'research commitment to vertebrates' are two different issues. Public demand for information about, and identification of, vertebrates is an information resource issue. This is the province of reference centres not research centres. Where research programs need to be restructured towards invertebrates, decision-makers should not be apprehensive. They can efficiently — and economically — service public interest in vertebrates by partially reallocating resources to reference centres.

In conclusion, and not least, reference centres in museums and their information services have the potential to greatly assist in popularizing Australia's invertebrate fauna — providing these services are adequately resourced and supported.

## ACKNOWLEDGEMENTS

Many people helped with the collation and analysis of the enquiry records since October 1986. Special thanks are extended to Tim Murrell, Elizabeth Drewe, Sybil Monteith, Vicki Sands, Roxanne Fawcett and Rona Gleeson. Discussions and comments on the manuscript were vigorously provided by Rhonda Scoullar, Steve Wilson, Glen Ingram and Jean Tilly.

## LITERATURE CITED

- CZECHURA, G.V. 1987. Workshop: Identifying animals. Pp. 54-55. In Czechura, G.V. & Scoullar, R. (eds), 'Conference '87: Museum Education Associations of Australia and New Zealand Biennial Conference 28 September-2 October 1987.' (Queensland Museum, Museum Education Association of Australia: Brisbane).
1993. The Pacific Baza *Aviceda subcristata* in southeastern Queensland: a review of natural history and conservation requirements. Pp. 196-208. In Olsen, P. (ed.), 'Australian raptor studies.' (Australasian Raptor Association, Royal Australasian Ornithologists Union: Mel-

- bourne).
- DEBLASE, A.F. & MARTIN, R.E. 1974. 'A manual of mammology.' (W.C. Brown Company: Dubuque).
- DIAMOND, A.W., SCHREIBER, R.L., PETERSON, R.T. & CRONKITE, W. 1989. 'Save the birds.' (Houghton Mifflin: Boston).
- FENECH, N. 1992. 'Fatal flight — the Maltese obsession with killing birds.' (Quiller: London).
- INGRAM, G.J. & RAVEN, R.J. (eds) 1991. 'An atlas of Queensland's frogs, reptiles, birds & mammals.' (Queensland Museum: Brisbane).
- LAMBLEY, P.W. & FRODIN, D.G. 1987. The Natural Sciences Resource Centre at the University of Papua New Guinea. *Curator* 30(3): 250-258.
- MADDEN, J.C. 1978. Bridge between research and exhibits — The Smithsonian Naturalist Centre. *Curator* 21(2): 159-167.
- PLOWMAN, K. 1994. Stories we tell about fauna. *Memoirs of the Queensland Museum* 36: 185-190.
- PONDER, W.F. 1994. Australian freshwater mollusca: conservation priorities and indicator species. *Memoirs of the Queensland Museum* 36: 191-196.
- SCOULLAR, R. 1989. The Queensland Museum Reference Centre. *Museum Education Association of Australia Journal* 28: 5-8.
1993. 'The Queensland Museum interpretive service: An evaluation.' (Unpublished M.Ed.stud. thesis, University of Queensland, St Lucia).
- SHIELD, J.M. & HARRISON, S. 1994. Invertebrate biodiversity conservation education: Experience with a Bendigo primary school. *Memoirs of the Queensland Museum* 36: 197-201.
- TAYLOR, K. 1992. The killing sites of Malta. *BBC Wildlife* 10(6): 69-70.



## GENETICS AND TERRESTRIAL MOLLUSC CONSERVATION

ADRIAN DANIELL

Daniell, A. 1994 06 30: Genetics and terrestrial mollusc conservation, *Memoirs of the Queensland Museum* 36(1): 47-53, Brisbane. ISSN 0079-8835.

Genetic analysis of populations provides information on the genetic structuring of populations and their breeding systems. Much of this type of information is presently not readily available for most invertebrates. Terrestrial molluscs are well known amongst geneticists for providing models of evolutionary phenomena. Both traditional and modern genetic analyses have been done on many species and these provide ideas which may be applicable to other molluscs as well as invertebrates in general. The genetic analysis of species in the native slug family Cystopeltidae is given as an example of the use of genetic analysis in the determination of structuring and breeding system. Comparisons are made to other terrestrial molluscs and the implications for their conservation discussed. □ *Genetics, population structuring, terrestrial mollusca, Cystopeltidae, slugs, captive breeding, Australia.*

Adrian Daniell, School of Genetics & Human Variation, La Trobe University, Bundoora, Victoria 3083, Australia; 6 August 1993.

Genetic diversity is the basis of biodiversity and the loss of genetic diversity means that a species or populations has a reduced ability to track long term environmental changes (Frankel, 1970; Frankel & Soule, 1981). One of the difficulties in trying to maintain genetic diversity is defining the level (e.g. population or species) at which genetic management should take place or how it could be done. There is no standard theory or method of assessing the desirable 'amount' of genetic variability a species or population 'needs' for long-term survival. The use of genetic data to decide on a 'quantitative basis' whether populations contain 'sufficient' genetic diversity to remain viable is still in its infancy despite great advances in techniques. Most ideas of genetic conservation have been based on a mixture of empirical data and on general genetic models which are yet to show predictive ability. However as more examples become available a more rational basis for biodiversity conservation should emerge.

The conservation of genetic diversity requires firstly an estimation of the extent of genetic variation within a species and within and between populations. Genetic analyses of a population can provide a reasonable method of determining not only the extent of population differences but also levels of inbreeding or selfing which may not be detected by direct observation or laboratory experiments. This is particularly true for the vast majority of invertebrates with little hope of breeding under controlled conditions to determine breeding system. Measures of the amount of gene flow between populations and species are

also possible, showing the extent of their isolation as well as testing validity of species status.

Terrestrial molluscs, as with most invertebrates, have been largely neglected in the species conservation debate. Apart from a few notable examples such as *Parula* (Johnson et al., 1986; Murray et al., 1988; 1991) and *Cerion* (Gould et al., 1974; Gould & Woodruff, 1978; Woodruff, 1989) genetic studies of terrestrial molluscs have been predominantly on the non-tropical northern hemisphere species. The bulk of these tend to concentrate on the highly polymorphic species such as *Cepaea* (Cain, 1983 & references there in; Murray, 1975). Considerable information is available for many European and north American species, and while representing a small proportion of all terrestrial species, do provide a general understanding of the dynamics of terrestrial mollusc populations. These studies show high levels of genetic differentiation between populations as well as a variety of breeding systems. In some instances different populations of the same species exhibited different breeding systems, i.e. outcrossing vs self-fertilization (Selander & Oehman, 1983; Foltz et al., 1982; Anderson & McCracken, 1986). Research on tropical species tend to be freshwater species involved in parasite transmission such as *Biomphalaria* (Mulvey et al., 1988; Vrijenhoek & Graven, 1992).

### MEASURING GENETIC DIFFERENCES

Various genetic analyses can be used to characterise the differences between populations and species. The average observed heterozygosity,  $H_0$

and the proportion of polymorphic loci,  $P$  are straightforward measures of the amount of genetic variability that can be used as general evaluation of a population. Populations in which  $H_0$  is zero are generally thought to be, in the case of molluscs, the result of self-fertilization. Self-fertilization takes place when sperm fertilizes an egg from the same individual. Low or zero values for  $P$  are also indicative of self-fertilizing populations. Other explanations for low values of  $H_0$  and  $P$  could be the result of population bottleneck, founder effects or strong selection forces (Frankel & Soule, 1981). However these measures don't take into account differences at specific loci and so different populations of the same species with the same  $H_0$  and  $P$  could still differ significantly in the alleles present. Other commonly considered measures are the so called  $F$ -statistics devised by Wright (1951) describe the arrangement of genetic variation in a subdivided population with two,  $F_{IS}$  and  $F_{ST}$  being the most useful.  $F_{IS}$  gives a measure of the non-random association of alleles within a population and can be used to infer the type of breeding system. Positive values indicate heterozygote deficiency, negative values an excess.  $F_{ST}$  is a measure of the genetic differentiation between populations. The average frequency of alleles found in only one population,  $\bar{p}(1)$  (Slatkin & Barton, 1989) can give an indication of actual allelic differences between populations. Where gene flow is restricted then the frequencies attained by these 'private' alleles will be high in comparison with populations where flow is greater. These alleles are useful in observing the direction of gene flow in small populations. The so called genetic distances, such as Nei's  $D$  and Rogers  $R$  are also routinely used to express the differences between populations and species. These two measures take into account the amount of allelic frequency differences and fixed differences between populations. The larger the value the more distant the populations or species.

#### AUSTRALIAN TERRESTRIAL MOLLUSCAN FAUNA

Inadequate genetic work has been carried out on the Australian mollusc fauna. Genetic analysis has been used to differentiate species, such as *Bothriembryon* in Western Australia (Hill et al., 1983), however little has been done on the genetic structuring of mollusc populations. The dynamic nature of many Australian ecosystems, particularly those of the south east, with habitat

mosaics caused by fires, would presuppose that many species of molluscs would show considerable genetic structuring. In other areas high biodiversity of species is reflected in genic structuring of populations. Woodruff & Solem (1990) found in the Kimberley region that the extensive radiation of camaenid snail species was accompanied by significant levels of genetic differentiation within species. Much more work has been done on freshwater species. For example Stoddart (1983) examined genetic variation in *Thiara balonnensis* while Ponder & Clark (1988) and Ponder (1994) have used allozymes for both species discrimination and examination of population structuring in freshwater snails. Some work has been done on introduced species. For example Johnson (1988) examined the founder effects and geographic variation in the introduced terrestrial snail *Theba pisana* in Western Australia. However, if conclusions on preserving genetic diversity are to be sound, genetic structuring in the common or widespread species also needs to be evaluated.

#### THE CYSTOPELTIDAE

Cystopeltidae is a family of slugs restricted to eastern Australia and found in a wide range of forest habitats (Smith & Kershaw, 1979). They appear to feed primarily on bark-dwelling micro algae and bacteria abundant in eucalypt forests. The family appears to be composed of mostly allopatric species which are discernible on morphological characters (Daniell, 1992). The analyses of various genetic measures of allozymes show that, as found with other terrestrial molluscs, species and populations show significant structuring (Table 1). Amongst the *Cystopelta* species mean  $H_0$  for populations ranged from 0.042 to 0.179 and  $P$  ranged from 0.16 to 0.36 values which are comparable with other terrestrial slugs (Foltz et al., 1982). A more detailed analyses of cystopeltid populations (Daniell, 1992) found that within species some populations exhibited very little or no variability and very low levels of heterozygosity. Within one species most populations had low to very low numbers of polymorphic loci. These results are indicative of selfing as is typical among many populations of slug species found in Europe (Foltz et al., 1984) although localized inbreeding as a result of colonisation by a few individuals or a massive population crash followed by a prolonged bottleneck can not be discounted. One difficulty with these types of measure is the effect

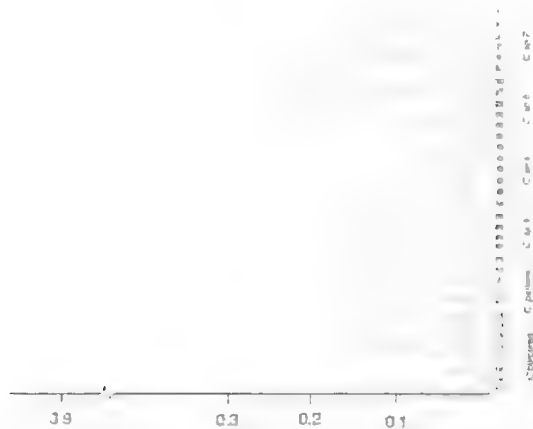


FIG. 1. UPGMA (unweighted pair group method) of Nei's genetic distances for *Cystopelta* species. Numbers refer to populations. Population 12 is of unknown taxonomic status.

of sampling area size. Sampling errors either being sampling 'populations' which are in fact panmictic or sampling over a larger area, which may encompass a number of discrete populations. In either case this will result in an incorrect interpretation of the genetic structure of the species. To overcome these types of errors a reasonable sampling regime requires an understanding of the organism's biology.

The  $F_{IS}$  values in cystopeltid species ranged from 0.05 to 0.55. These indicate heterozygote deficiency which may be the result of localised inbreeding or selfing. Despite these results most populations appear to be outcrossing with most values of  $F_{IS}$  being non-significantly different from zero.  $F_{ST}$  values between populations ranged from 0.192 to 0.661 and indicate that there is considerable subpopulation heterogeneity. This is not an unexpected outcome as most terrestrial molluscs have poor dispersal ability and so can exhibit extensive population structuring even on a relatively small scale. Ochman et al.

(1987) found mean  $F_{ST}$  values for both *Cepaea nemoralis* and *C. hortensis* of approximately 0.20 between demes. Stiven (1989) found mean values of  $F_{ST}$  of 0.065 and 0.116 for two species of *Mesomphix* in north America. The Populations of the introduced species *Theba pisana*, in Australia, had  $F_{ST}$  values as great as 0.301 (Johnson, 1988). Selander & Whittam (1983) found extensive differentiation within populations of *Helix aspersa* introduced into California.

Geographic distances between populations in these studies varied from adjacent populations to those separated by as much as 25km, with high levels of genetic differentiation being largely independent of the actual distances. As with  $F_{IS}$  values,  $F_{ST}$  results for the cystopeltids show a large variation between species. The variability of values is indicative of the chance factors affecting which alleles exist and in what frequency in each population. Founder effects, drift, selection along with breeding system all play a part in shaping the genetic make-up of a population. There also appears to be no significant correlation between the level of genetic differentiation and geographic distance between populations (Daniell, 1992). As suggested by Kemperman & Degenars (1992) sampling regime may have a big influence in the genetic structure found. They found that genetic difference within subspecies of *Albinaria* were detectable at distances of less than 200m. In the case of cystopeltids a detailed examination of a single locality, (*C. purpurea* population 17) samples from three sites 140m apart, had a  $F_{ST}$  value of 0.015, a magnitude less than those found for the species as a whole. This suggests, at least for this species, that deme size could be quite large. Therefore sampling for any genetic analysis should encompass detailed ecological parameters so that subsequent results can have some conservation significance.

Genetic distances (Fig. 1) show a similar picture to the other measures with no consistency of

TABLE 1. Species, number of subpopulations, average population size, average heterozygosity  $H_0$ , proportion of polymorphic loci  $P$ , mean  $F_{IS}$ , mean  $F_{ST}$ .

SPECIES	No. of Subpops	Av. N	$H_0$	$P$	$F_{IS}$	$F_{ST}$
<i>C. apelta bicolor</i>	1	2	0	0	0	0
<i>C. petterdi</i>	3	18.3	0.08	0.21	0.07	0.47
<i>C. purpurea</i>	7	36	0.18	0.32	0.32	0.37
<i>C. purpurea PO</i>	3	24.6	0.16	0.36	0.39	0.015
<i>C. sp. 1</i>	6	21.6	0.03	0.21	0.55	0.66
<i>C. sp. 2</i>	5	18.8	0.07	0.16	0.05	0.53
<i>C. sp. 3</i>	5	12.6	0.18	0.32	0.16	0.19

genetic distances between populations within species. This could be expected, because as demonstrated by  $F_{ST}$  values, structuring of the populations is not uniform, reflecting the different evolutionary histories of each population. A detailed examination of *Albinaria* species (Kemperman & Degenaars, 1992) showed a similar situation, where populations of different species and subspecies showed marked variation in genetic similarity. Clearly not all populations are equal and this suggests that populations are a more useful unit of conservation than species. The other significant feature is the usefulness in highlighting the possibility of previously undescribed species, particularly in widespread and variable organisms. What does the genetic data tell us about terrestrial mollusc populations? Firstly, it is unlikely that a single species can be used as general model for a family. Variability between cystopeltid species for all genetic measures used was high, with no consistent trend. Secondly detailed analyses of populations (Daniell, 1992) indicates, as found from other studies, that populations themselves can differ significantly from the species average for genetic measures. In some cases one population could exhibit the characteristics of a selfing population ( $H_0$  &  $P$  of zero) and another could be polymorphic and largely outcrossing.

It is yet to be established that populations with high levels of genetic variability are more 'successful' than those with less. While the general case is that variability is needed for evolutionary processes to take place, and little or no variability in a population is a long-term disadvantage (Frankel & Soule, 1981) very high levels of variability have not been shown to be of highest benefit. There is strong evidence that levels of heterozygosity can have an influence on various fitness characters. In marine bivalves *Mytilus* spp. heterozygosity has been correlated with increased growth rates and adult survival (KoeHN & Gaffney, 1984) and in *Placopeeten magellanicus* heterozygosity at one locus was associated with increased mobility (Volckaert & Zouros, 1989). For both these examples the mechanism appears to involve the reduced metabolic requirements of heterozygous individuals, although this may more significant when the organism is in a more stressful environment (Skihiniński & Roderick, 1989). Triggs & Sherley (1993) correctly point out that the amount of variation within populations is as important as between. Where a species consists of a number of populations each exhibiting a high level of

genetic variability then any single one could contain a significant representation of the alleles in that species. In contrast species which have low variability within populations then more than one populations would be needed to maintain genetic variability within the species.

The study of co-adapted genes in land snails has concentrated on the more obvious features such as shell pattern and colour (Cain, 1983; Cook, 1986; Goodhart, 1987) and body colour (Cowie, 1990). Cryptic species or those which are less subjected to visual selection and so little in the way of 'obvious' characters are available to study. In the case of minute snail species, such as the punctids and charopids whose movements are restricted by size and the risk of desiccation, they appear to be restricted to microhabitats and therefore possibly adapted to small isolated populations. These populations have probably undergone severe bottleneck events and so through inbreeding or even selfing may exhibit low levels of heterozygosity and polymorphic loci. As yet no genetic analyses has been done on the minute Australian species but Cook & Luce (1993) looked at, among other things, genetic structuring in the small helicoid *Heterostoma paupercula* (Gastropoda: Helicidae). These snails live under rocks on sparsely vegetated oceanic islands and the  $F_{ST}$  value was found to be 0.435, not an unexpected result. Heterozygosity was also less than expected. However, other large and apparently more mobile groups such as the cystopeltids can also exhibit high  $F_{ST}$  values. This may reflect a common feature of terrestrial mollusc populations; high levels of genetic differentiation. This in itself may be a product of the low mobility and dispersal capabilities of terrestrial molluscs in general.

#### GENETIC MANAGEMENT OF INVERTEBRATE POPULATIONS

At its most fundamental genetics provides a measure of the genetic diversity and distribution in species and populations. The genetic structuring of a population reflects its evolutionary history. The high levels of genetic differentiation observed in molluscs mean that some caution should be applied to their genetic management. As such, any modification of genetic structure through captive breeding or translocation is fraught with uncertainty. For example the mixing of two unrecognised species or genetically distinct populations could result in disruption of particular gene combinations and reducing fit-

ness. Any program of captive breeding will lead to some selection for the ability to thrive in captivity which may be detrimental to any future re-releases into the 'wild'. Species that do well in captivity may be 'pre-adapted' to the situation as a result of the changes that led to it becoming endangered and may not provide a general model for all species. As can be observed in the case of *Partula* not all species, even if closely related, are thriving in captivity (Tonge & Bloxam, 1991). The idea of preserving a 'single' species would also present difficulties particularly in the case where many genetically distinct populations can be observed. Which populations should then be preserved? It has been suggested that the greater the genetic distance between populations the higher the preservation priority (Triggs & Sherley, 1993). This would presuppose that one could predict which population and hence which combination of alleles is likely to be the most successful. This approach also ignores the role of rare or restricted alleles in future evolution in populations and species. Crozier (1992) proposes that populations be the most appropriate unit for preservation, and genetic distance data be used as a basis of population ranking, the rationale being that not all populations within a species are 'equal'.

The detailed analyses of genetic structuring should be done *before* species become endangered or at risk. The current mode of genetic evaluation is *after* a species is recognized to be in a difficult position, by which time genetic disruption may have already occurred. This is made a less reliable approach owing to the generally poor state of the basic biology of a species and difficulties in devising a sampling protocol. A more complete understanding of non endangered species may give an insight into the 'normal' genetic structure to populations, however it is unlikely with the current level of understanding of population dynamics that simple models will be available to 'predict' the outcome of disrupting the genetic structure of a population through captive breeding or translocation. The genetic protocol produced for the Moorean *Partula* species (Tonge & Bloxam, 1991) sets a bench mark for other such programs. As a general model for breeding programs however it is somewhat limited since the *Partula* species had been thoroughly studied well before extinction in the wild became inevitable (Clarke & Murray, 1969). Populations were well enough known to be sure that samples were from panmictic populations. This is in contrast with the majority of species

where the level of knowledge of their basic biology, let alone their genetics, is poor. General principles need to be established to provide guideline for the management of invertebrate species. It is clear from the difficulties with husbandry of *Partula* species (Tonge & Bloxam, 1991) that captive breeding is a last resort. The role of genetic factors in the decline of a species is in most cases not the most important factor. Where genetics does contribute is in clarifying the dynamics of populations especially where other methods of observation are unlikely to provide answers, such as estimating breeding systems and gene flow. It is also useful in taxonomic studies, particularly where morphology is highly variable or in the case of minute species difficult work with because of size and difficulty in finding specimens. In the case of *Cystopelta* a large sized, widespread and common organism was found to have many more species than previously described. As new techniques become available it will be possible to more rapidly evaluate genetic structuring and breeding system.

The situation is urgent for many terrestrial molluscs. The currently estimated number of species, around 30,000, is probably a gross underestimation. Genetic analysis has shown that in most species significant genetic differentiation exists even in those which are common and widespread. This is probably indicative of the levels of speciation that are occurring in particular in tropical species. It would be a first step if captive breeding and population re-establishment of species into previously known ranges to test the applicability of techniques. It would also be of some benefit that institutions such as zoos could become involved in the display and breeding of local molluscs species both to foster some local interest and also to develop expertise well before it is needed.

#### ACKNOWLEDGMENTS

Thanks are due to Neil Murray for supporting my work into what was at the time the obscure area of Australian indigenous mollusc population genetics. Thanks also to the School of Genetics and Human Variation La Trobe University for access to laboratory and computer facilities.

#### LITERATURE CITED

- ANDERSON, J.B. & MCCracken, G.F. 1986. Breeding system and population genetic structure in philomycid slugs (Mollusca: Pulmonata). *Biological Journal of the Linnean Society* 29: 317-329.

- CAIN, A.J. 1983. Ecology and ecogenetics of terrestrial molluscan populations. Pp. 597-647. In Russell-Hunter, W.D. (ed.), 'The Mollusca 6: Ecology' (Academic Press: London).
- CLARKE, B. & MURRAY, J. 1969. Ecological genetics and speciation in land snails of the genus *Partula*. *Biological Journal of the Linnean Society* 1: 31-42.
- COOK, L.M. 1986. Polymorphic snails on varied backgrounds. *Biological Journal of the Linnean Society* 29: 89-99.
- COOK, L.M. & LACE, L.A. 1993. Sex and genetic variation in a helioid snail. *Heredity* 70: 376-384.
- COWIE, R.H. 1990. Climatic selection on body colour in the land snail *Theba pisana* (Pulmonata: Helicidae). *Heredity* 65: 123-126.
- CROZIER, R.H. 1992. Genetic diversity and the agony of choice. *Biological Conservation* 61: 11-15.
- DANIELL, A.J. 1992. 'Taxonomy, genetic and ecology of the terrestrial slug family Cystopeltidae (Mollusca: Pulmonata)'. (Unpublished PhD thesis, La Trobe University, Burwood).
- FOLTZ, D.W., OCHMAN, H., JONES, J.S., BOWLER, J.S., EVANGELIST, S.M. & SELANDER, R.K. 1982. Genetic population structure and breeding systems in arionid slugs (Mollusca: Pulmonata). *Biological Journal of the Linnean Society* 17: 225-241.
- FOLTZ, D.W., OCHMAN, H. & SELANDER, R.K. 1984. Genetic diversity and breeding systems in terrestrial slugs of the families Limacidae and Arionidae. *Malacologia* 5: 593-605.
- FRANKEL, O.H. 1970. Variation the essence of life. Sir William Macleay Memorial Lecture. *Proceedings of the Linnean Society* 95: 158-169.
- FRANKEL, O.H. & SOULÉ, M.E. 1981. 'Conservation and evolution'. (Cambridge University Press: Cambridge).
- GOODHART, C.B. 1987. Why are some snails visibly polymorphic, and others not? *Biological Journal of the Linnean Society* 31: 35-58.
- GOULD, S.J. & WOODRUFF, D.S. 1978. Natural history of *Cerion* VIII Little Bahama Bank - a revision based on genetics, morphometrics and geographic distribution. *Bulletin of the Museum of Comparative Zoology* 148: 371-415.
- GOULD, S.J., WOODRUFF, D.S. & MARTIN, J.P. 1974. Genetics and morphometrics of *Cerion* at Pongo Carpet: a new systematic approach to the enigmatic land snail. *Systematic Zoology* 23: 518-535.
- HILL, A., JOHNSON, M.S. & MERRIFIELD, H. 1983. An electrophoretic and morphological examination of *Bothriembryon kendricki* (pulmonata: Bulimulidae), a new species previously considered conspecific with *B. bulla* (Menke). *Australian Journal of Zoology* 31: 227-242.
- JOHNSON, M.S. 1988. Founder effects and geographic variation in the land snail *Theba pisana*. *Heredity* 61: 133-142.
- JOHNSON, M.S., MURRAY, J.J. & CLARKE, B.C. 1986. Allozyme similarities among species of *Partula* on Moorea. *Heredity*, London 56: 319-327.
- KEMPERMAN, C.M. & DEGENAARS, G.H. 1992. Allozyme frequencies in *Albinaria* (Gastropoda: Pulmonata: Clausilidae) from the Ionian Islands of Kephallinia and Ithaka. *Malacologica* 34: 3-61.
- KOEHN, R.K. & GAFFNEY, P.M. 1984. Genetic heterozygosity and growth rate in *Mytilus edulis*. *Marine Biology* 82: 1-7.
- MULVEY, M.C., NEWMAN, M.C. & WOODRUFF, D.S. 1988. Genetic differentiation among West Indian populations of the schistosomic-transmitting snail *Biomphalaria glabrata*. *Malacologia* 29: 309-317.
- MURRAY, J.J. 1975. The genetics of Mollusca. Pp. 3-31. In King, R.C. (ed.), 'Handbook of genetics' (Plenum Press: New York).
- MURRAY, J.J., MURRAY, E., JOHNSON, M.S. & CLARKE, B. 1988. The extinction of *Partula* on Moorea. *Pacific Science* 42: 150-153.
- MURRAY, J.J., STINE, O.C. & JOHNSON, M.S. 1991. The evolution of mitochondrial DNA in *Partula*. *Heredity*, London 66: 93-104.
- OCHMAN, H., JONES, J.S. & SELANDER, R.K. 1987. Large scale patterns of genetic differentiation at enzyme loci in the land snail *Cepaea nemoralis* and *Cepaea hortensis*. *Heredity* 58: 127-138.
- PONDER, W.F. 1994. Australian freshwater mollusca: conservation priorities and indicator species. *Memoirs of the Queensland Museum* 36: 191-196.
- PONDER, W.F. & CLARK, G.A. 1988. A morphological and electrophoretic examination of '*Hydrobia buccinoides*', a variable brackish-water gastropod from temperate Australia (Mollusca: Hydrobiidae). *Australian Journal of Zoology* 36: 661-689.
- SELANDER, R.K. & OCHMAN, H. 1983. The genetic structure of populations as illustrated by molluscs. *Isozymes: Current Topics in Biological and Medical Research: Genetics and Evolution* 10: 93-123.
- SELANDER, R.K. & WHITTAM, T.S. 1983. Protein polymorphism and the genetic structure of populations. Pp. 89-114. In Nei, M. & Krakauer, R.K. (eds), 'Evolution of genes and proteins'. (Sinauer: Sunderland, Massachusetts).
- SKIBINISKI, D.O.F. & RODERICK, E.E. 1989. Heterozygosity and growth in transplanted mussels. *Marine Biology* 102: 73-84.
- SLATKIN, M. & BARTON, N.H. 1989. A comparison of three indirect methods for estimating average levels of gene flow. *Evolution* 43: 1349-1368.
- SMITH, B.J. & KERSHAW, R.C. 1979. 'A field guide to the non-marine molluscs of South Eastern Australia'. (ANU Press: Canberra).
- STIVEN, A.E. 1989. Population biology of two land snails (*Mesomphix* spp.): variation among six



- southern appalachian sites with differing disturbance histories. *Oecologia* 79: 372-382.
- STODDART, J.A. 1983. The accumulation of genetic variation in a parthenogenetic snail. *Evolution* 37: 546-554.
- TONGE, S. & BLOXAM, Q. 1991. A review of the captive-breeding programme for Polynesian tree snails. *International Zoo Yearbook* 30: 51-59.
- TRIGGS, S.J. & SHERLEY, G.H. 1993. Allozyme genetic diversity in *Plectostylus* land snails & implications for conservation. *New Zealand Journal of Zoology*. 20: 19-34.
- VOLCKAERT, F. & ZOUROS, E. 1989. Allozyme and physiological variation in the scallop *Placopacten magellanicus* and a general model for the effect of heterozygosity on fitness in marine molluscs. *Marine Biology* 103: 51-61.
- VRIJENHOEK, R.C. & GRAVEN, M.A. 1992. Population genetics of Egyptian *Biomphalaria alexandria* (Gastropoda, Planorbidae). *Journal of Heredity* 83: 255-261.
- WOODRUFF, D.S. 1989. Genetic anomalies associated with *Cerion* hybrid zones: the origin and maintenance of new electromorphic variants called hybridzymes. *Biological Journal of the Linnean Society* 36: 281-294.
- WOODRUFF, D.S. & SOLEM, A. 1990. Allozyme variation in the Australian camaenid land snail *Cristilabrum primum*: a prolegomenon for a molecular phylogeny of an extraordinary radiation in an isolated habitat. *The Veliger* 33: 129-139.
- WRIGHT, S. 1951. The genetical structure of populations. *Annals of Eugenics* 15: 323-354.

# VARIATIONS IN DIVERSITY OF MANGROVE CRABS IN TROPICAL AUSTRALIA

PETER J.F. DAVIE

Davie, P.J.F. 1994 06 30: Variations in diversity of mangrove crabs in tropical Australia. *Memoirs of the Queensland Museum* 36(1): 55-58, Brisbane, ISSN 0079-8835.

Species richness of crabs in seven estuaries in tropical northern Queensland and one in the Northern Territory varied markedly. Greatest diversities were found in the Queensland wet tropics and the Northern Territory site. Long periods of seasonal aridity combined with small estuary sizes have probably led to reduced diversity in the 'dry' tropics despite the lower latitude. □ *Diversity, tropics, ecology, biogeography, Crustacea, Decapoda, Brachyura, mangroves, intertidal, Australia, Queensland.*

Peter J.F. Davie, Queensland Museum, PO Box 3300, South Brisbane, Queensland 4101, Australia; 22 April 1994.

Mangrove communities have a diverse and specialised invertebrate fauna. Molluscs and crabs are the largest and most conspicuous elements of them. Although mollusc and crabs are equally diverse, crabs can be up to five times the biomass of other invertebrates (Golley et al., 1962). Crabs play a pivotal role in the health, functioning, and community structure of mangrove forests mainly through their burrowing and feeding activities. Few ecological studies on larger species show that burrowing and feeding activities of crabs are important (Jones, 1984; Robertson, 1991; Smith et al. 1991).

Mangroves are seen as murky, mosquito-infested wastelands and past collectors have shown disinterest in getting 'good-and-muddy'. Hence, mangrove crabs are still poorly known. More than 120 species in eight families are associated with Australian mangroves, and over 20% of these are unnamed (Davie, 1982). Revisionary taxonomy of Australian mangrove crabs continues (Lucas & Davie, 1982; Davie, 1988, 1989, 1990, 1992, 1993a, b, 1994).

Two families, Grapsidae and Ocypodidae, contain almost all common mangrove inhabitants. Nearly half of all crab species in Australian mangroves are endemic to Australia. Mangrove forests on temperate coasts of New South Wales, Victoria and South Australia, are rarely extensive. Their sparse fauna is shared with adjacent rocky shore and mudflat habitats. Towards the tropics, mangrove tree species are more diverse and mangrove forests can occupy vast areas. Complexity of habitats yields a high diversity of mangrove crabs.

Knox (1963) recognised two marine coastal biogeographic tropical/sub-tropical provinces—Damperian and Solanderian Provinces. The first stretches north from about 28°S on the Western

Australian coast to encompass north Australia as far as the Torres Strait; and the second extends along the east coast from Torres Strait to 25°S. Davie (1985) reviewed distributions of mangrove crab species. Results roughly agreed with these provinces. My recent data suggest, however, that the region south of the Kimberly on the west Australian coast is also an area of endemism, with at least five endemic species. Strong separation of indigenous faunas implies a long independent evolution of coastal wetland ecosystems.

## METHODS

Eight estuaries in northern Australia (Fig. 1) were visited for taxonomic studies in winter/spring, as sites are generally inaccessible during wet summers. Time spent at each site varied but, on at least three days, two people collected intensively at low-tide. All different habitats from seaward fringes at the mouth to the upstream limit of tidal influence were targeted. Collection was by digging with shovels, sieving, careful scrutiny of foliage, and breaking open fallen timber and logs. They were qualitative not quantitative. Collecting effort was roughly comparable for all sites and reliably reflected the number of species present. Data from other sites are not reliably complete. Full species lists for each site are available from the author.

## RESULTS

The Murray River, just north of Cardwell, and Trinity Inlet, Cairns, show similar very high diversities. The next most diverse estuary is the Starcke River, c.150km north of Cooktown. The Murray and Starcke are similar sized small estuaries with comparable mangrove forest



FIG. 1. Study sites in Queensland.

development. Even though Starcke is c.380km north it has c.25% fewer crab species than the Murray River (Table 1). Two other sites north on the east coast both shared similar diversity but it was about half of those of the two Wet Tropics sites. East Alligator River in Kakadu, by contrast, has a high crab diversity but this is not different from the Cairns region, even though it is far more northerly and closer to the Indo-Malayan Archipelago, long considered the most diverse region anywhere.

I found other small rivers in northeastern Queensland, e.g. Claudie and Pascoe near Iron

Range, very sandy with sparse mangrove development and apparently very low crab diversities. The evidently large North Kennedy system entering Princess Charlotte Bay may often carry freshwater and be of interest; it has not been sampled here.

Ocypodids are fewer in the 'dry tropics' (Table 1). These almost exclusive burrowers feed by scouring sediment, so their lower diversity may reflect the trend towards sandier substrates in many small estuaries of the dry tropics.

## DISCUSSION

Alongi (1989, 1990) reviewed work on the tropical soft-bottom benthos. He showed that while species diversity indisputably increases with increasing latitude, the tropics are far from homogenous and alpha biodiversity is the result of local environmental conditions. Moore (1972) argued that extreme conditions in the tropics can place intertidal species under greater physical stress than their temperate relatives; this should be reflected in diversity in a given area and time.

Effects of regional conditions on species diversity of mangrove vegetation has been demonstrated (Semeniuk, 1983; Wells, 1982, 1983, 1985; Smith & Duke, 1987). Smith & Duke (1987) found differences between 'eastern' (east of the Great Dividing Range) and 'western' (west of Torres Strait across northern Australia) mangrove forests. In eastern forests, longer estuaries with large catchments tend to have more species than those that are shorter and have smaller catchments. Also, high interannual rainfall variability and frequent cyclones depress species richness. These factors showed no evident correlation with species richness in western forests where the most important physical deter-

TABLE 1. Numbers of crab species in eight north Australian estuaries.

REGION	LOCALITY	GRAPSIDAE	OCYPODIDAE	OTHER FAMILIES	TOTAL
OLD DRY TROPICS					
NW Cape York	Laradeenya Ck	12	4	2	18
	Andoom Ck, Weipa	5	5	3	13
NE Cape York	Muddy Bay	8	8	8	24
	Harmer Ck	15	7	2	24
	Starcke R.	14	10	10	34
QLD WET TROPICS	Cairns	16	15	13	44
	Murray R.	16	16	15	47
N.T.	E. Alligator R.	19	12	10	41

minant was the amount of freshwater seepage from the rearward terrestrial fringe. The amount of yearly rainfall per se did not effect diversity but high variability was crucial.

Alongi (1987a, b; 1988a, b) found that microbial and meiofaunal communities in mangroves of north Queensland fluctuated significantly over time but mostly showed no obvious seasonality. Nematodes had low to moderate species diversity and few species per habitat but also, species composition varied from 35-90% seasonally. He attributed that to duration and intensity of monsoonal rains.

Crab survey data herein similarly suggest that small area diversity is greater in mangrove systems of high rainfall humid tropics of north-eastern Queensland, from about Townsville to the Daintree, than in the more tropical, but seasonally drier, mangrove systems that have been studied. Many catchments in the watershed of the Great Dividing Range provide year round estuarine conditions with relatively reliable freshwater drainage. By contrast, small river systems of Cape York have estuarine parts for only a few months each year. They are effectively completely freshwater during the monsoon season and merely marine intrusions during the dry. Many mangrove crabs have specific salinity requirements both for adults and larval development and therefore need year-round estuarine conditions. Long periods of negligible rainfall and high temperatures can also lead to intolerable conditions such as parched soil and/or hypersaline soil porewater (>90 ppt) (Semeniuk, 1983). Low rainfall followed by seasonal scouring also means sandy or gravelly substrates are more common, which – because of the predominance of sediment feeders – typically means a lower diversity. The 'dry tropics' zone could be implicated in the biogeographic separation of eastern and northern Australian faunas (Davie, 1985) because of large distances lacking complex estuarine environments.

## CONCLUSION

Crab diversity is crucial to, and an indicator of, productivity of mangrove areas. In eastern Australia, the most productive mangrove estuaries coincide with large human settlements and are therefore most threatened. All swamps are not the same, and this should be addressed during planning for mangrove habitat, and biodiversity, management. If the function of different mangrove systems are properly compared,

we must address potential differences in species composition and effects these might have.

## ACKNOWLEDGEMENTS

I am very grateful to members of the Australian Littoral Society whom I accompanied into the field on many occasions, and in particular Peter Shanco and Eddie Hegerl. John Short, Queensland Museum, is also especially thanked for braving swamps with me and providing laboratory support. John Short and Leslie Newman provided helpful comments on the manuscript.

## LITERATURE CITED

- ALONGI, D.M. 1987a. Intertidal zonation and seasonality of meiobenthos in tropical mangrove estuaries. *Marine Biology* 95: 447-458.
- 1987b. Inter-estuary variation and intertidal zonation of free-living nematode communities in tropical mangrove systems. *Marine Ecology Progress Series* 40: 103-114.
- 1988a. Bacterial productivity and microbial biomass in tropical mangrove sediments. *Microbial Ecology* 15: 59-79.
- 1988b. Microbial-meiofaunal interrelationships in some tropical intertidal sediments. *Journal of Marine Research* 46: 349-365.
1989. Ecology of tropical soft bottom benthos: a review with emphasis on emerging concepts. *Revista de Biologia Tropical* 37: 73-88.
1990. The ecology of tropical soft-bottom benthic ecosystems. *Oceanography and Marine Biology Annual Review* 28: 381-496.
- DAVIE, P.J.F. 1982. A preliminary checklist of Brachyura (Crustacea: Decapoda) associated with Australian Mangrove Forests. *Opereculum* 5: 204-7.
1985. The biogeography of littoral crabs (Crustacea: Decapoda: Brachyura) associated with tidal wetlands in tropical and sub-tropical Australia. In Chappell, J., Davie, J.D.S., & Woodroffe, C., (eds), 'Coasts and tidal wetlands of the Australian Monsoon region'. Proceedings of a conference held on 4-11 November 1984, Darwin. (N.A.R.U. Monograph Series: Darwin).
1988. A new genus and species of goneplacid (Crustacea: Brachyura) from Queensland, Australia. *Memoirs of the Queensland Museum* 25: 259-64.
1989. A re-appraisal of *Heteropanope* Stimpson, and *Pilumnopus* A. Milne Edwards (Crustacea: Decapoda: Pilumnidae) with descriptions of new species and new genera. *Memoirs of the Queensland Museum* 27: 129-156.
1990. New and rare crabs of the subfamily Dotillinae (Crustacea: Ocypodidae) from northern

- Australia and New Guinea. Memoirs of the Queensland Museum 28: 463-473.
1992. Revision of *Sarmatium* Dana (Crustacea: Brachyura: Sesarminae) with descriptions of three new species. Memoirs of the Queensland Museum 32: 79-97.
- 1993a. A new genus of macrophthalmine crab (Crustacea: Decapoda: Ocypodidae) from eastern Australia. Records of the Australian Museum 45: 5-9.
- 1993b. A new species of sesarminae crab (Brachyura: Grapsidae) from Japan and Taiwan, previously known as *Sesarma erythodactyla* Hess, 1865. Crustacean Research 22: 65-74.
1994. Revision of the genus *Neosarmatium* Serène and Soh (Crustacea: Brachyura: Sesarminae) with description of two new species. Memoirs of the Queensland Museum 35: 35-74.
- GOLLEY, F., ODUM, H.T. & WILSON, R.F. 1962. The structure and metabolism of a Puerto Rican red mangrove forest in May. Ecology 43: 9-19.
- JONES, D.A. 1984. Crabs of the mangal ecosystem. Pp. 89-109. In Por, F.D. & Dor, I. (eds) 'Hydrobiology of the Mangal'. (W. Junk: The Hague).
- KNOX, G.A. 1963. The biogeography and intertidal ecology of the Australasian coasts. Oceanography and Marine Biology 1: 341-404.
- LUCAS, J.S. & DAVIE, P.J.F. 1982. Hymenosomatid crabs of Queensland estuaries and tidal mud flats, including descriptions of four new species of *Elamenopsis* A. Milne-Edwards and a new species of *Amarinus* Lucas. Memoirs of the Queensland Museum 20: 401-419.
- MOORE, H.B. 1972. Aspects of stress in the tropical marine environment. Advances in Marine Biology 10: 217-269.
- ROBERTSON, A.I. 1991. Plant-animal interactions and the structure and function of mangrove forest ecosystems. Australian Journal of Ecology 16: 433-443.
- SEMIENIUK, V. 1983. Mangrove distribution in northwestern Australia in relationship to regional and local freshwater seepage. Vegetation 53: 11-31.
- SMITH III, T.J. & DUKE, N.C. 1987. Physical determinants of inter-estuary variation in mangrove species richness around the tropical coastline of Australia. Journal of Biogeography 14: 9-19.
- SMITH III, T.J., BOTO, K.G., FRUSHER, S.D. & GIDDINS, R.L. 1991. Keystone species and mangrove forest dynamics: the influence of burrowing by crabs on soil nutrient status and forest productivity. Estuarine, Coastal and Shelf Science 33: 419-432.
- WELLS, A.G. 1982. Mangrove vegetation of northern Australia. Pp. 57-78. In Clough, B.F. (ed.), 'Mangrove Ecosystems in Australia' (A.N.U. Press: Canberra).
1983. Distribution of mangrove species in Australia. Pp. 57-76. In Teas, H.J. (ed.) 'Biology and ecology of mangroves'. (W. Junk: The Hague).
1985. Grouping of tidal systems in the Northern Territory and Kimberly region of Western Australia on presence/absence of mangrove species. Pp. 167-186. In Chappell, J., Davie, J.D.S., and Woodroffe, C., (eds) 'Coasts and tidal wetlands of the Australian Monsoon region'. Proceedings of a conference held on 4-11 November 1984, Darwin. (N.A.R.U. Monograph Series: Darwin).

# HERITAGE LISTING OF INVERTEBRATE SITES IN SOUTHEASTERN AUSTRALIA

PENELOPE GREENSLADE

Greenlade, P. 1994 06 30: Heritage listing of invertebrate sites in southeastern Australia. *Memoirs of the Queensland Museum* 36(1): 67-76. Brisbane. ISSN 0079-8835.

A pilot project has been carried out to examine the feasibility of listing sites on the National Estate Register based on invertebrates values. As a result, 30 sites in southeastern Australia have been nominated. The criteria used for registration were the same as those used for registration of cultural, historical and other natural sites. The method of selecting sites is described and all sites for which nominations were prepared are briefly discussed together with the reasons for listing them. The majority of sites were small, discrete habitats (for example, mountains tops, caves and remnant patches of vegetation) that contained a rare species of Gondwanan relationships. About one third was on private land and nearly half was 10ha or less in size. The major threats were tourism and recreation followed by alteration of hydrological characteristics. It was found that taxa that are not site specific cannot easily be protected by National Estate listing. I conclude that listing has value. It gives a measure of protection to habitats and alerts the wider community to their value. It has advantages over protecting individual species because, in practice, it is possible to legislate for only a few species and such legislation does not simultaneously confer protection on the species' habitat. □ *Invertebrates, National Estate, southeastern Australia, listing.*

Penelope Greenslade, South Australian Museum, North Terrace, Adelaide, South Australia 5000; present address; c/o CSIRO, Division of Entomology, GPO Box 1700, Canberra, A.C.T. 2601, Australia; 31 July 1993.

The protection of invertebrate biodiversity in Australia is now accepted as an issue worthy of serious consideration in conservation. Attempts to protect invertebrates, however, are hampered by what has been termed 'the taxonomic impediment'. To that should be added the 'distributional and ecological impediments', since lack of information of the ecology and distribution of species is similarly limiting. Further, protection by listing invertebrate species individually is obviously impractical in an estimated fauna of over 200,000. Moreover, a network of reserves selected to represent all vegetation associations, will not protect all invertebrates, of which a proportion, estimated at about 10%, have highly localised distributions and are not bound to any recognised vegetation type.

It follows that conservation of invertebrate biodiversity should be through protection of species' habitats. Nominating specific invertebrate habitats for National Estate listing is one method of protecting them. This is the only method that is currently economically possible in most States. Once sites are listed, however, they are not legally protected as reserves, but listing gives them an established measure of protection from developments, in particular from those by government bodies.

The criteria for listing sites are specific and are formulated so that they can be applied to all types of sites from aboriginal cave paintings to the Great Barrier Reef and the Sydney Opera House. Those that are relevant to invertebrates are listed in Table 1, although it should be noted that no definition of a rare or endangered species is given by the Australian Heritage Commission (AHC).

Although several thousand sites had been listed on the National Estate Register in Australia for their natural or cultural values, up to 1990, none had been listed solely for invertebrate values. Consequently, the AHC established a project to examine the feasibility and value of listing invertebrate sites and began with a pilot scheme in southeastern Australia. It was decided 30 sites in Victoria, New South Wales, South Australia and the Australian Capital Territory would be a good basis for assessing the feasibility of extending the project nationwide.

I report the results of the AHC pilot study in this paper.

## METHODS

For the consultation process, it was important that as many professional and amateur inver-



TABLE 1. Criteria for the register of the National Estate compiled by the Australian Heritage Commission November 1988 that are relevant to invertebrate values.

1.1	Be important in the evolution of Australian fauna.
1.2	Be important in maintaining existing processes of natural systems at the regional or national scale.
1.3	Be important in exhibiting unusual richness or diversity of fauna.
2.1	Be important for rare, endangered or uncommon fauna, communities, ecosystems or phenomena.
3.1	Be important in demonstrating the principal characteristics of the range of ecosystems, the attributes of which identify them as being characteristic of their class.
4.1	Be important for their close associations with individuals whose activities have been significant within the history of the nation, state or region.
5.1	Be important as places highly valued by a community for reasons of educational associations.
7.1	Be important for information contributing to wider understanding of Australian natural history by virtue of their use as research sites, teaching sites, type localities, reference or benchmark sites.

tebrate biologists as possible be approached during the process of selecting sites for nomination. To this end, the project was advertised through the Australian Entomological Society's quarterly newsletter and a poster was exhibited at the Society's annual meetings of 1991 and 1992.

A committee of three persons, including an amateur naturalist, was established in each state to solicit suggestions, consider their relevance to the criteria and assess the feasibility of preparing a nomination. As far as possible, all relevant collectors were consulted and often the nomination was completed by the person suggesting the site. In Victoria, only taxa that had been listed by the *Flora and Fauna Guarantee Act 1988* (see Butcher et al., this volume) were chosen. In the other States, where legislation of this kind did not exist, the sites were chosen to cover as wide a range of different taxa, ecosystems, biomes and types of site as possible.

The nomination form was comprehensive and nearly thirty pages long. The information sought was as follows:

The exact location and boundaries of the nominated site were required, including details of ownership, current usage and size; and names of the State and Local administrative area in which it was found. A detailed description should follow including geological, botanical as well as faunistic information, all of which should be thoroughly referenced. Five pages of multiple choice options covering the same information was next with the inclusion of landscape characteristics. Then there were three pages dealing with the significance of the site, which had to be carefully detailed both with reference to the Heritage criteria, and in a separate discussion. The integrity and condition of the site then had to be documented, requiring a visit to it, and then a justification of the boundaries was requested. Lastly,

there was space for a bibliography and names and addresses of personal contacts. Attachments were requested, some of which were mandatory, including maps at various scales (three is normally the minimum) photographs of the site and illustrations of the invertebrates present. Other relevant documents (e.g. copies of scientific papers and reports) could be attached. Preparation of a nomination usually took about two weeks.

Once received by the Heritage Committee, the nomination was rigorously checked and refereed by the Commission's own officers. Two committee stages had to be passed before proceeding to the final stage, which entailed publication on an 'Interim List' in the press for public comment. These comments had to be considered before the site was finally accepted on the register and entered into the data base. Consistency of standards was ensured internally by the Heritage Commission, in particular during scrutiny by the Board of Commissioners.

In assessing nominations, the most straightforward were those that had species and habitats that were highly localised. The species tended to be those of high conservation value because they were apparently rare and/or living in habitats particularly sensitive to disturbance. Mostly they were species of Gondwanan relationships, which often occurred on sites such as mountain tops, caves or isolated water bodies.

Because this was a pilot project investigating the feasibility and wider application of nominations, it was decided to include at least one site representative of each of the criteria in Table 1. Sites were generally selected so that a representative range of reasons for listing were included, e.g. significant type localities; historical and educational importance; rare and en-

dangered species; and high species richness. One nomination (Castlereagh Woodlands) protected the habitat of a diverse non-site specific taxon, the jewel beetles. It listed remnant native vegetation over a large area, including corridors, to allow for movement of the beetles, thereby increasing the possibility of detecting host plants; and buffering against unpredictable environmental variability.

Suggestions for nominations amounted to several hundred possible sites. From these, 30 were chosen as representative of the whole. Sites that were the only known habitat of a genus, or higher taxon, were selected in preference to those containing merely an endemic species of a more widely distributed genus because areas of endemism for higher (supra-specific) taxa carry more 'phylogenetic diversity' than those with only endemic species. For practical reasons, sites for which there was most information were preferred.

Sites carrying the following taxa emerged as priorities for nomination:

1. Gondwanan relict species, often described as 'living fossils' whose distributions were well-known.
2. Taxa occupying geographically discrete sites such as mountain tops, caves, sink holes and mound springs, whose distributions were well-known because the habitat was well-defined.
3. Taxa that congregate at some point during their life history, such as Lepidoptera on hill tops and in various aestivation/hibernation sites, whose distributions were also relatively well-known.
4. Taxa presently occupying a severely fragmented habitat in remnant vegetation but, from historical records, are believed to have once been more widespread.

Sites could not be nominated for taxa that were not strongly tied to particular localities. Some examples are given below:

1. Large groups of species belonging to the highly diverse endemic radiations in Australia with distributions often centred in the *Acacia/Eucalyptus* woodlands and forests. Examples are found among the Psyllidae, Eurytomidae (Hemiptera), Chrysomelidae and Curculionidae (Coleoptera) and Oecophoridae (Lepidoptera). Sites that contained non-site specific taxa, however, could qualify if the fauna was unusually diverse because the diversity was site specific.
2. Taxa that might be rare but were also highly vagile, e.g. King Stag Beetle, *Phalacrognathus muelleri* (Macleay), a Canberra gryllacridid, *Coorabnoruma canberrae* Rentz, and the Golden Stag Beetle, *Lamprima aurata* Latreille, of South Australia. Also impractical for listing were microhabitats

TABLE 2. Summary of taxa for which nominations were prepared.

Taxa	No. of Sites	Taxa	No. of Sites
Oligochaeta	1	Diptera	1
Crustacea	2	Coleoptera	4
Araneae	1	Lepidoptera	7
Plecoptera	3	Hymenoptera (Formicidae)	1
Odonata	1	Mollusca	1
Ephemeroptera	1	Various	5
Orthoptera	1		

that were unpredictably impermanent despite the long period of time they took to develop, for example, rotten logs, fungal fruiting bodies (bracket fungi), moss and deep leaf litter. These microhabitats were not site specific.

It also became clear that sites in remote regions were difficult to nominate because of the difficulty of access. This was particularly relevant in the case of the mound springs and Ooldea Soak sites, which were not directly visited.

A number of other taxa or sites were suggested but found to be inappropriate for nomination:

1. Undescribed species. Until a species is described and compared with other congeners by a specialist taxonomist, there is no certainty about its status (e.g. whether it is new or, in fact, an already described species). As well, its distribution is not accurately known (e.g. whether it is restricted, or widespread and common) nor are its relationships. All this information was needed to make a decision for National Estate listing.
2. Sites thought to meet the criteria based on undescribed species were also unsuitable for the reasons given above.

Furthermore, if undescribed species were deemed acceptable, there was a danger that misguided, even fraudulent, claims could be made that were impossible to confirm or disprove, thus trivializing the process of listing.

## NOMINATIONS

### VICTORIA

Nominations for eight sites were submitted to the Heritage Commission and entered on the interim list.

1. Two years ago the only known site for the 'living fossil' mayfly, *Hemiphyscia mirabilis* (Selys), was a single swamp in Wilsons Promontory National

TABLE 3. Summary of land tenure

Tenure	No. of Sites
Privately owned land	9
Recreation reserves usually managed by the local council	8
Within an existing National or Conservation Park or similar reserve	6
Pastoral lease	3
Land under the control of the Forestry Commission	3
Crown land leased to the Department of Defence	2
Unallocated Crown land	1
Miscellaneous leased Crown land (for educational purposes, for waste dumps or rubbish pits etc.)	

Park. The site was vulnerable to damage from grazing, bush fires and possibly overcollecting. The species has since been found on Flinders Island and in extreme NE Tasmania.

2. The Giant Gippsland Earthworm, *Megascolides australis* (McCoy), occurs in a fairly limited, well-defined area of east Gippsland, which includes Mt Worth National Park, but also on grazed, private land. Populations are said to be declining as a result of intensive agricultural practices and overcollecting. The most significant distribution on private land was nominated. Mt Worth National Park was already listed on the National Estate and the species was added to that existing nomination.
3. The Warragul Burrowing Crayfish, *Engaeus sternalis* (Clarke), appears to be restricted to the banks of a creek in a council reserve where it is under threat from soil compaction due to trampling by stock and recreational use. The strip of creek bank that supported natural vegetation was nominated.

Three stonefly sites were nominated, all three occur on mountain tops:

4. The large Mt Stirling Stonefly, *Thaumatoperla flaveola* (Burns & Neboiss), is restricted to fast flowing streams at high altitudes on four peaks in eastern Victoria. An area of 10km<sup>2</sup> encompassing most of its distribution was nominated. Some sites have been destroyed by developments for ski resorts and populations are declining because of increased recreational activities in the area.
5. The Mt Donna Buang Stonefly, *Riekoperla darlingtoni* (Illies), is small and wingless and restricted to an area within 1km of the summit. Its habitat is small temporary streams under closed forest, which is threatened by heavy visitation and the building of more tourist facilities such as car parks.
6. The Otway Ranges contain a rare, large primitive

stonefly, *Eusthenia nothofagi* (Zwick). Only a few specimens were known until it was recently recollected from two small sites. Both these sites have been nominated and are within National or State Parks. The sites are threatened by forestry activities, including land clearance, which alters stream characteristics.

The last two sites in Victoria are important hill-topping sites for butterflies.

7. Since the nomination was submitted, the Mt Piper butterfly community has been studied intensively. It includes at least two threatened lycaenids: Small Ant-blue, *Acrodipsas myrmecophila* (Waterhouse & Lyell) and the Large Ant-Blue, *A. brisbanensis cyrilus* (Anderson & Spry). Its natural values are now very much appreciated by the local community as a significant feature of the town. The site is being rehabilitated and appears secure. It is described and discussed in more detail by Jelinek et al. (this volume).
8. A series of small dunes, only 4km<sup>2</sup> in area, in mallee country, NW Victoria, supports a unique assemblage of butterflies including the rare and endangered Small Brown Azure (*Ogyris otanes* Felder & Felder). The location is being kept confidential to protect the species from overcollecting. Damage from placement of a trig point and access road has occurred recently.

#### AUSTRALIAN CAPITAL TERRITORY

Two sites were selected for nomination and have been placed on the interim list.

1. *Keyacris scurra* (Rehn) is a morabine grasshopper whose distribution has decreased since settlement. It now occurs only in small disjunct patches of native *Themeda* grassland or *Chryscephalum* herbfield. One small population (ca. 2000 individuals) in Tidbinbilla National Park could be subject to damage by recreation and fire. The 0.5ha of land carrying the population was nominated.
2. Castniids are a family of conspicuous dayflying moths. One species, *Synemon plana* Walker, was widespread in southeastern Australia before settlement, according to early collection records. It is now restricted to a few remnant patches of *Danthonia* grassland. The largest of these, the Belconnen Naval Station, was nominated but it is scheduled for resumption by the State Government for urban expansion.

#### NEW SOUTH WALES

Ten sites have been nominated in this State and all have been submitted:

1. Harrington-Crowdy Head rainforest in the northern part of the State is a strip of littoral rainforest in good condition, about 4km long, which is the type

TABLE 4. Summary of habitats, ecosystems, biomes and vegetation types.

Habitat	No. of Sites
Caves	1
Sink holes	1
Mound springs	1
Swamps, soaks, creeks	2
<b>Landscape units</b>	
Mountain and hill tops	8
Creeks	3
Remnant vegetation	7
Cliff tops, coastal strips	4
Rangelands and pastoral	3

Landscape units (except caves, sink holes and springs) can be further broken down into vegetation types as follows:

Vegetation types	No. of Sites
Rainforest	
littoral	1
gallery	1
cool temperate	1
subtropical	2
Grassland	1
Herbfield	1
Low shrubland	1
Eucalypt forest	
open	5
tall open	2
Eucalypt woodland	
open	1
low open	1
Mallee heath	3
Coastal heath	2
<b>More than one vegetation type</b>	
Tall open eucalypt forest, alpine and subalpine vegetation	1
Shrubland, heathland and swamp	1
Shrubland, woodland, tussock grassland	1
Sedgeland, heath	1
Low open woodland, tall shrubland, heath, sedgeland	1

locality for several dipteran and coleopteran species. It is an important research site because the fauna is exceptionally diverse. Threats to the site's integrity include invasion by weeds. A number of other relict patches of rainforest, which are of heritage value, occur along the coast in the region. Many of them are unallocated Crown land, as is the Harrington-Crowdy Head site.

2. *Paralucia spinifera* Edwards & Common, the Bathurst Copper, is one of Australia's rarest butterflies yet no populations occur in reserves. There is some evidence that it is in decline, possibly through overcollecting. Of the two sites nominated (4ha) in total area, one is leased from the Crown for use as a rifle range and the other is freehold and used as a coal mine. The natural values of both sites are being eroded by horses, control burning and recreation. The food plant also is being affected.
3. One of the richest hill-topping sites for butterflies in northern N.S.W. is Mt Ramornie, on private land west of Grafton. Forty-nine species have been recorded there and it is the only known location for *Acrodipsas arcana* (Edwards & Miller). All land carrying native vegetation within the landholder's boundary was nominated. A number of other important hill tops for butterflies occur in the region.
4. Carrai Bat Cave, NW of Kempsey, is within a flora reserve administered by the Forestry Commission of N.S.W. Several invertebrates of importance live in the cave including *Progradungula carraiensis* Forster & Gary, a relictual, gondwanan spider that is only known from here. It is suggested that threats to the cave's integrity could come from over-use by speleological groups.
5. The Wog Wog patch experiment, established in 1985 and scheduled to run indefinitely, is located within the tall eucalypt forest of southern N.S.W. (Nicholls & McKenzie, this volume). Replicate patches of three sizes of native eucalypt forest surrounded by pine forest and control sites within intact forest have been sampled for eight years for invertebrates using pitfalls. The beetle fauna documented so far consists of nearly 650 species, a remarkably high diversity for a small area of relatively uniform eucalypt forest.
6. Fowler's Gap, situated in arid rangelands 100km north of Broken Hill, is the research station of the University of N.S.W. Numerous collections of invertebrates and ecological projects have been centred on the site during the last 25 years. Over 30 publications, mostly on Formicidae and Caliphoridae, have been the result. It is probably the best known site for invertebrates in the rangelands of N.S.W.
7. The Macleay family, active throughout the 19th century, were the first locally-based entomologists to make major collections of Australian insects. Family diaries have been published and the vast collections resulting from their work are now housed in the Macleay Museum, Sydney Univer-

TABLE 5. Summary of criteria used and all registrations.

Categories	No. of Sites
Sites with 'rare and endangered' taxa	15
Primarily species rich sites	7
Primarily type localities	3
Sites primarily with a close association with significant individuals	1
Research and/or teaching sites, bench mark sites	2
Sites which are primarily important in maintaining existing processes or natural systems at the regional or national scale	2

sity. Rope's Creek in western Sydney was a favourite collecting spot of W. Macleay and an important type locality for Buprestidae (jewel beetles). This locality has become degraded and now lacks any substantial native habitat. The Castlereagh State Forest, 3km to the north, is intact and other native vegetation remnants persist within an area of 10km<sup>2</sup> reaching as far as the University of Western Sydney's Hawkesbury campus, where many of Macleay's species are still found. Most of the land is Crown land. Present land use includes forestry, waste dumps, correctional services and educational sites. All relatively intact native vegetation within this area was nominated including corridors linking major remnants.

8. Mooney Mooney Creek is a holotype site for several species of Diptera, being an unusually diverse site for the order. A number of rare species are found here that are absent from nearby reserves. For this reason alone, nomination is justified. The fauna is relatively well-known because it has been regularly visited by collectors for over 30 years. Two uncommon species of Mecoptera are also found here.
9. Rotary Park within the city of Lismore is a recreation park and has the only known habitat for the large flightless carabid, *Nurus brevis* Motschulsky. The species was more widespread before the Big Scrub was cleared for agriculture. The park was already listed and the carabid was added to the registration. Rainforest is currently being restored on this site.
10. Alexandra Park near Astonville is the only known locality for *Nurus atlas* (Castelnau), also more widespread before vegetation clearance. It is a council recreation reserve and already listed as part of the National Estate. The beetle has been added to the existing registration.

#### SOUTH AUSTRALIA

Ten sites have been nominated in this State:

1. *Hypochrysops ignitus* (Leach), the Fiery Jewel, is extremely rare in South Australia and considered

endangered. One small site on which it occurs is within the Innes National Park, York Peninsula. It is the only site known where it uses *Dodonaea humilis* as a host plant. The vegetation is coastal heath and scattered woodland and is threatened by wild fire. Three other uncommon butterflies occur on the site.

2. Another very small site (100m × 200m) of coastal heath in the same park is habitat for the rare butterfly, *Ogyris olives*, already referred to in nomination 8 in Victoria's mallee. This species was much more widespread in South Australia earlier this century. As with the Fiery Jewel site, the greatest threat to the site is wild fire.
3. The 'dinosaur ant', *Nothomyrmecia macrops* Clark, said to be very primitive, is known only from a small patch of mallee on private land adjacent to the township of Poochera, Eyre Peninsula. A roadside site was inadvertently destroyed soon after discovery and the current population, which occurs in only 600m<sup>2</sup>, is threatened by invasion by exotic weeds and a pest species of snail. Another population of uncertain status may occur adjacent to the town cemetery. The site was nominated together with a large area of potential habitat, which is mallee, but with a predominantly exotic grassy understorey.
4. The middle to upper slopes of Darke Peake, Eyre Peninsula, an isolated quartzite ridge with native vegetation, is the only known locality for *Nanodectes bulbicercus* Rentz. This species was certainly more widespread before land clearance for agriculture. Although the whole mountain range is already listed, the land is owned by the Australian National Railways and is in use as an expanding quarry, which seriously detracts from the National Estate values. This is one of a number of sites that need protection for rare and restricted termitoids.
5. Tookayerta Creek in the Mt Lofty Ranges has been noted as the most speciose site for Plecoptera (6 out of 8 species) and Ephemeroptera (6 out of 14 species) in the State. It is in private hands, heavily weed infested and its banks eroded by stock.
6. Fossil Cave is a sink hole in the southeast and the type locality for the 'living fossil' *Koonunga crenarum* Zeidler, a syncarid crustacean. The cave is also an important site for vertebrate pleistocene fossils. It is an example of many similar sink holes or drowned caves in the region, all of conservation importance.
7. 'Mygale Blowhole' or Nullarbor Cave Number SN 253, is the sole known site for the only cave adapted trapdoor spider known, *Troglodiplura lowryi* Main. This spider is not related to any Australian spider group and its closest relatives are in South America. Fragments of specimens have been found in two other caves on the Nullarbor further north, but no live specimens. It might previously have been more widespread in caves in the region but became extinct as they became drier.

TABLE 6. Summary of threatening processes

Threatening process	No. of Sites
Tourism/recreation	12
Altered hydrological characteristics as a result of changed land use	8
Pastoral activity	7
Land development, urbanisation	6
Wild fires	6
Overcollecting	5
Weed invasion	5
Other disturbance by government instrumentalities, Telecom, trig points, etc	3
Sites with no perceived threats	2
Forestry activities	2
Arable agriculture	2
Mining and exploration	2
Controlled burning	1

Aldinga Scrub Reserve, just south of Adelaide, is one of the very few remnants of vegetation left on the Adelaide Plain. It is already listed on the Register but invertebrate values were not included with the original nomination. It is an important habitat for species previously widespread on the plains and a recent survey documented at least 540 species of invertebrate from the Reserve. These are now being added to the site's registration.

9. Hallett Cove is also already on the National Estate Register but it is also the locality for some rare Lepidoptera and the most westerly outlier of the Blue Meat Ant *Iridomyrmex lividus* Shattuck. The invertebrate fauna has been added to the previous listing.
10. Ooldea Soak used to be the railhead before the line linking Western Australia and South Australia was built. This site was nominated partly because it is an important type locality, particularly for Coleoptera and Hemiptera, but also because of its historical association with significant personalities in the development of entomology in Australia. In the early part of this century, Arthur Lea, who described more species of Australian beetle (5432) than anyone before or since, and later Norman Tindale, visited this remote site by train and collected intensively. Parts of the area around the soak are already listed because of its association with Daisy Bates and aboriginal culture. A different, larger area, which is likely to have been within range of insect collectors on foot from the railhead, and including mallee vegetation, has been nominated.

Mound springs are not included in this list, but nominations will be prepared in a separate, future project. The mound springs are known to harbour

a highly endemic fauna of aquatic invertebrates, of which Crustacea and Mollusca are foremost (Ponder, this volume). All natural, unfenced springs are in urgent need of protection from trampling by stock and tourists. Management is difficult because of the springs' remoteness. The Neales Springs group includes some of the most important individual springs and invertebrate additions to existing nomination of Blanche Cup and Dalhousie Springs, where a blind amphipod occurs, will be made. Most other groups of springs such as Emerald Spring, which is the only locality known in Australia for macrostomid platyhelminths, fulfil the criteria for nomination.

## DISCUSSION

The value of National Estate listing for sites with natural values has been demonstrated many times. The most publicised cases have been concerned with threats from logging to National Estate listed forests, where listing has prevented some unwise, commercial exploitation. Undoubtedly, listing is a powerful social barrier. It is too early to say what effects listing will have on the protection of invertebrate sites, although the process itself has conferred a number of benefits in raising awareness of invertebrate conservation in general.

The results of the pilot project are summarized in Tables 2-6 and illustrate some priorities in insect conservation. As might be expected, butterflies lead the list of taxa nominated because they are the best known group of invertebrates in Australia (Table 2). Within that order, lycaenids, which have a complex life cycle including a symbiotic relationship with ants, are represented disproportionately. This indicates that species can be more vulnerable if they have a complex life cycle with multiple dependencies on other plant and animal species.

Otherwise, the taxa selected showed no biases except towards those for which there were Australian specialists familiar with their systematics and distributions (Table 2). An obvious gap is the myriapods, which reflects the lack of taxonomic expertise for the group, and not that there are no rare or endangered myriapods.

A summary of the land tenure of all sites shows that the largest number of sites were either on private land or in Recreation Reserves (Table 3). These areas are not so well protected as those in Conservation Reserves. National Estate listing could prove to be of benefit here, especially in



drawing the attention of owners and managers to the natural values of their land.

Although one aim for the project was to select as wide a range of different types of sites as possible, nevertheless many of those selected were hills or mountain tops (Table 4). This probably reflects their relative pristine nature as well as their conservation importance for invertebrates. The main vegetation associations involved appear to represent fairly well those present in the region of the pilot study (Table 4).

Most sites were small with only a third being larger than 100 hectares and another third smaller than 5 ha (Fig. 1, 2). This illustrates the importance of small areas for the conservation of invertebrates, but does not obviate the need for much larger areas for the conservation of many Australian taxa. Priority was given to the most vulnerable and rare taxa at the beginning of the pilot study and it became clear that many of these taxa were also associated with small sites.

Table 5 lists the most important reasons for nomination. For half the sites, the criterion used was that of containing rare and endangered fauna while species richness was relevant to nearly a quarter of the sites. The justification for listing any one site, however, was not usually based on a single feature but on a range of characteristics.

Tourism and recreation were the most frequent-

ly cited threatening processes (Table 6), which may reflect, to some extent, a bias in selecting sites about which there was most information because they were accessible. Altered hydrological properties was the next most common threat, probably because a large proportion of the nominations were wetlands. Surprisingly, pollution from run-off carrying pesticides and nitrates was not mentioned, although it is likely to be an as yet undetected danger to some sites.

Pastoral activities, urbanisation, fire and weed invasion were also considered to be serious threats. Significantly, overcollecting was thought to be a threatening process for five of the sites.

## CONCLUSION

The pilot study demonstrated that listing invertebrate sites was feasible. Of those nominated, about half have been processed by the Commission and placed on the Interim List (1993). It should be stressed that the 30 sites nominated in this study were only a small sample. Many more sites could have been nominated.

There has been some criticism of National Estate listing because a large number of invertebrate species, for which there is no information, were not and cannot be included. However,

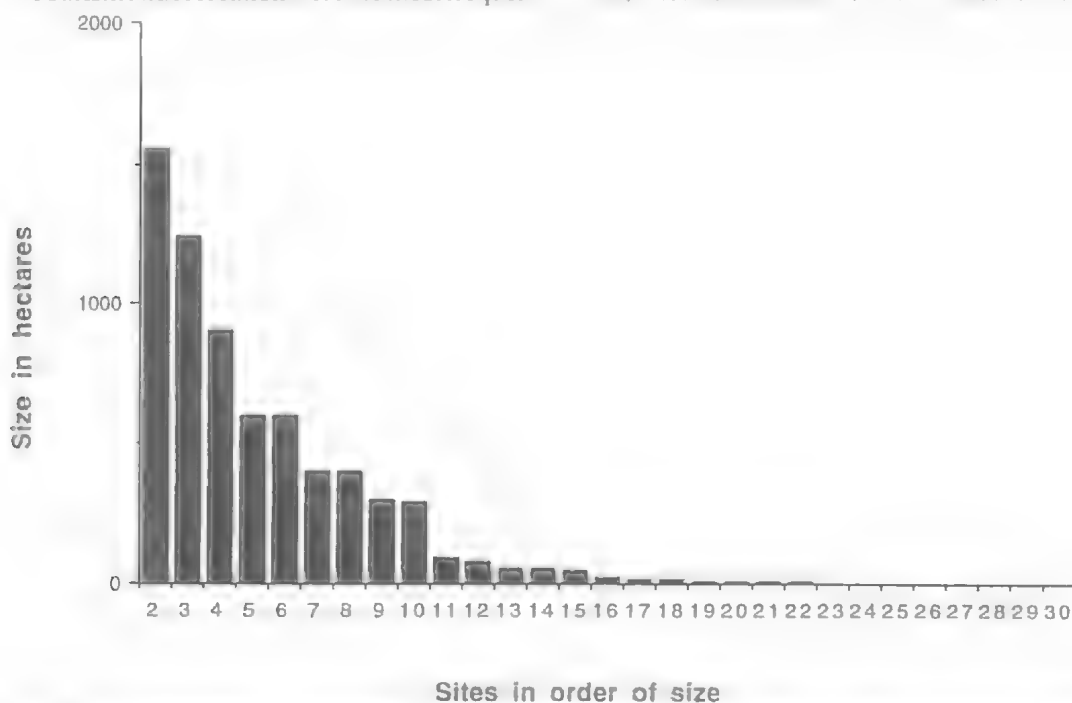


FIG. 1. Size in hectares of sites nominated in decreasing order omitting the largest, (Fowler's Gap) of 38,889ha.

this is no reason to withhold listing for those that can. Moreover, it is precisely the taxa which are of most phylogenetic and conservation interest that have attracted most attention from taxonomists and, therefore, about which most is known.

National Estate listing does not and cannot take into consideration all factors for the long-term survival of the species, but the process is vital in focusing attention on species for which recovery or action plans are needed, and for facilitating such plans. Although listing confers no legally binding obligations, owners have almost invariably welcomed information on the invertebrate fauna of their land: no negative attitudes were encountered. The only exception was from officials of a local council, who were indifferent to the proposed listing.

I list the benefits of National Estate listing below:

1. Listing gives a measure of protection to habitats, in particular, by alerting the wider community to their value. It has advantages over protecting individual species because legislation is only practical for small numbers of species and, even then, legislation does not simultaneously confer protection on habitats.
2. Sites with all types of land tenure can be listed including private land. Permission from land owners need not be sought but they are always consulted by the Australian Heritage Commission before listing occurs and encouraged to continue protection of the site.
3. National Estate listing has been criticised because it is said that the legislation is not strong enough to prevent destruction of a listed site. State and Local Governments need not consider National Estate listing when giving planning or development approvals, but many States do. The Federal government is, however, obliged to do so, although under the Act it can over-ride listing. State planning bodies, at least in the A.C.T and South Australia, keep lists of registered sites for consultation when assessing planning applications. The Inter-governmental agreement on the environment signed by all States except Tasmania, in February 1992, states that the States and Commonwealth 'agree that the register of the National Estate is one of the factors that the States may consider when making land use and resource planning decisions... The parties recognise... that some applications of S.30 of the Act (Australian Heritage Commission Act 1975) may have significant land and resource use planning implications' (my emphases).
4. Registration has an important benefit because consultation has to be undertaken during preparation of the nomination with a wide range of people includ-

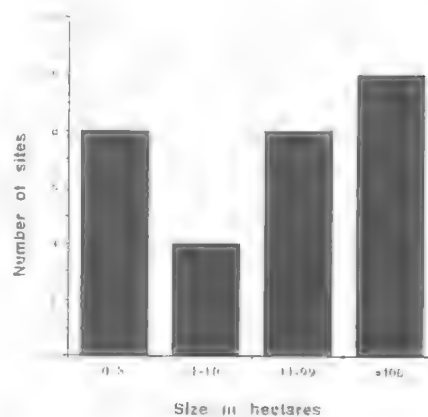


FIG. 2. Nominated sites classified into four groups by increasing size.

ing: both professional and amateur biologists, land-owners, government employees (of different kinds and at all levels), non-governmental organisations and some members of the public. This results in a wider appreciation, not only of the conservation of Australian invertebrates, but also of the value and widespread applicability of National Estate listing for the protection of Heritage.

5. Preparing a nomination involves research on the taxon (or group of taxa) for which protection is sought and also on the ecological and other features of the site itself. The nomination therefore provides baseline data from which action, recovery or other management plans can be written. Documenting threatening processes at every site has been most valuable in this respect. An example is *Nothomyrmecia macrops*, which has been studied intensively by taxonomists and behaviourists, but for which management issues had so far been neglected.
6. Because of our lack of taxonomic, ecological and distributional knowledge of much of Australian invertebrate biodiversity, there are inherent difficulties in protecting it. Adequate protection is dependent on having a sufficiently large pool of taxonomic expertise. Through nomination, well-known species can act as umbrella species for the suite of lesser-known invertebrates that are part of the same ecological community.
7. An original prediction of about a hundred invertebrate sites for the whole of Australia was underestimated by at least one order of magnitude. Four States still have to be considered and there remains an extensive list of sites from southeastern Australia, compiled during the course of this project, for which nominations have yet to be prepared.

#### ACKNOWLEDGEMENTS

The work on which this paper is based was

carried out as part of a project supported by funds made available by the Commonwealth of Australia under the National Component of the 1990-91 National Estate Grants Program. The program is administered by the Australian Heritage Commission.

The following people prepared or gave major assistance with nominations; J. Anderson, G. Carruthers, R. Coy, E. Dexter, R. Fisher, M. Gray, A. Greig, C. Margules, J. Roberts, and G. Williams. Others provided information or photographic material and contributed in various different ways: F. Badman, D. Britton, D. Cosby, E. D. Edwards, W. Green, P. J. M. Greenslade, G. Gross, C. Harris, D. Hayston, W. Horning, P. Horwitz, P. Horne, A. Jelinek, K. Key, R. Kitching, J. Lawrence, P. Lillywhite, I. Lundy, D. McAlpine, M. MacBriar, A. McLennan, P. McQuillan, E. Matthews, J. Matthews, G. Milkevits,

C. G. Miller, J. Moffitt, G. B. Monteith, B. P. Moore, K. and L. Mudge, F. Neumann, T. R. New, V. Pettigrove, W. Ponder, D. C. F. Rentz, B. Richardson, P. Souter, A. Sundholm, R. W. Taylor, B. Van Praagh, A. Yen, W. Zeidler. I am most grateful to all these people. Many others contributed in less major, but no less essential, ways but are too numerous to list here. I would particularly like to thank also Michael Mulvaney, AHC, who initiated the project and provided patient support throughout.

#### LITERATURE CITED

References to data listed in the paper are numerous and are all recorded on the nominations, copies of which are available from the author and the Australian Heritage Commission.

## CANOPY ARTHROPOD DIVERSITY OF NEW CALEDONIAN FORESTS SAMPLED BY FOGGING : PRELIMINARY RESULTS

ERIC GUILBERT, JEAN CHAZEAU AND LYDIA BONNET DE LARBOGNE

Guilbert, E., Chazeau, J. & Bonnet de Larbogne, L. 1994 06 30: Canopy Arthropod Diversity Of New Caledonian Forests Sampled By Fogging : Preliminary Results. *Memoirs of the Queensland Museum* 36 (1): 77-85. Brisbane. ISSN 0079-8835.

Faunal composition and community structure of canopy arthropods was analyzed from insecticidal fogging samples in 3 types of New Caledonian forests: dense evergreen forest on ultramafic alluvium (Rivière Bleue), sclerophyllous forest on limestone and conglomerate (Pindai) and sclerophyllous forest on schists (Païta).

Mean arthropod density in both sclerophyllous forest was significantly higher than in the dense evergreen forest. Without considering the introduced ant *Wasmannia auropunctata* which occurs in both sclerophyllous forests, the prevalent orders are Collembola in evergreen forest, Psocoptera in both sclerophyllous forests, and Diptera (Nematocera) in all 3 forests. The 3 forests are characterized by the prevalence of non-insect predators (mostly Araneae) and epiphyte grazers. *W. auropunctata* is the prevalent group in the sclerophyllous forest of Païta but not in Pindai.

In spite of its ecological imprecision, the fogging method is still a faster and easier way to obtain information on global biodiversity which is most urgently needed for monitoring ecologically sensitive areas in tropical forests. □ *Insecticide fogging, New Caledonia, forests, canopy, arthropods.*

Eric Guilbert, Muséum national d'Histoire naturelle, Laboratoire d'Entomologie, 45 rue Buffon, 75005 Paris, France; Jean Chazeau & Lydia Bonnet De Larbogne, ORSTOM, Zoologie appliquée, B.P. A5, Nouméa, New Caledonia; 6 August 1993.

Arthropod communities in rainforest canopies have attracted increasing interest during the last 20 years, in relation to the development of fogging techniques first introduced by Martin (1966; Roberts, 1973; Erwin, 1982; Stork, 1988). In particular, the use of these techniques by Erwin (1982) provided the first projection of total richness of the biosphere and initiated further works on this subject (Stork, 1988; May, 1990).

New Caledonia has been recognized as one of the 'hot spots' of biodiversity (Myers, 1988). In the last eight years, many taxonomic descriptions have significantly increased knowledge of its fauna (e.g., Tillier, 1988; Chazeau & Tillier, 1991; Matile, Naji & Tillier, 1993). However, very little is still known of the arthropod fauna of the canopy.

It seems now necessary to go beyond classical taxonomical descriptions in order to allow comparisons of local diversities and raise local interest for conservation of the most representative threatened natural biotas. To study diversity patterns, sampling should account for spatial and seasonal variations of taxonomical groups. For this purpose, we have implemented a fogging method adapted to local conditions. Preliminary results on 3 types of New Caledonian forests are discussed here.

## METHODS

### SAMPLING SITES

Three sampling sites were selected in two forest types. Two sites are relictual sclerophyllous forests, on limestones and conglomerates in Pindai (North Province, alt. 30m) and on schists in Mt. Nondoué, Païta (South Province, alt. 110m). The third site is located in dense evergreen forest on ultramafic alluvium in Rivière Bleue Provincial Park (South Province, alt. 160 m). The Païta and Pindai sites were included formerly in a botanical survey of the New Caledonian sclerophyllous forests (Jaffré et al., 1993). The Rivière Bleue site was described by Bonnet de Larbogne et al. (1991) and a comprehensive study of its vegetation was given by Jaffré & Veillon (1991). Species richnesses of forest phanerogames amount to 102, 108 and 219 in Païta, Pindai and Rivière Bleue sites, respectively.

In each site, we used 40 x 1<sup>2</sup> collectors grouped in 4 neighbouring plots of 10 collectors that maximised stability of data and allowed us to analyse spatial heterogeneity within plots and between plots. Spatial analysis will not be discussed here. One plot covers an area of 30-40m<sup>2</sup> and one site corresponds to 350-400m<sup>2</sup>. Each site was

Table 1. Climate and weather conditions during fogging at each site.

Average conditions (nearest location)	Païta	Népouï	Ouénarou
Temperature: 1961-90	23°C	23°C	21.5°C
Annual rainfall: 1971-90	1191mm	913mm	2518 mm
Conditions during fogging (at the sites)	Païta	Pindaï	Rivière Bleue
Temperature	16°C	15°C	11°C
R.H.	84%	92%	94%

sampled 4 times a year in order to cover seasonal variations. We here analyse results from the first sampling made during the dry season (30 June/16 July 1992).

#### FOGGING & COLLECTING

A portable fogging machine (Dyna-fog Golden Eagle Backpack 2980) was used to generate a fast killing fog from a mixture of Cyfluthrin, water and polyhydric alcohols (400cc of Solfac EW 050 in 4 litres of Maxifog solvent). The 4 plots of each site were sampled consecutively early in the morning, 4 minutes each, within a time c.20-30 minutes in each site. The moderate height of the canopy in Rivière Bleue and Païta (15-25m) and in Pindaï (8-12m) allowed operation from ground level. The machine manipulated from the ground, propelled the fog upwards, but successful sampling required strict weather conditions, without any wind nor rain (see Table 1). White heavy plastic collecting sheets were hung with rubber bands on 1m x 1m square iron frames raised 0.5 or 0.8m above the ground on removable sticks, which allowed attainment of a horizontal level for the trays even on steep slopes. All arthropods which had dropped on sheets after two hours were collected by washing with water and wetting agent. A two hour drop-time was recommended as optimal by Erwin (1983) and Stork (1987). The liquid was filtered then through a double screen (0.6mm and 0.3mm), and the specimens collected were stored in 95% alcohol. Washing and filtering were carried out in the field.

The specimens were sorted to order level for all arthropod taxa and at family level for Araneae, Hymenoptera, Hemiptera, Coleoptera and Diptera (Appendix). Arthropod taxa were assigned to guilds as defined by Stork (1987), Moran & Southwood (1982) and Basset (1991).

Statistical analysis has been performed using the SAS package. Non-parametric tests (Kruskal-Wallis test and Wilcoxon 2-sample test) were used to compare the data which were still not

Table 2 a, b. Comparison of mean abundance of total arthropods (Total) including and excluding *W. auropunctata* (without *W.*).

a (upper). Comparison for 3 sites by Kruskal-Wallis Test (Chi-Square ( $\chi^2$ ) Approximation, Df=2). b (lower). Comparison for 2 sclerophyllous forests by Wilcoxon 2-Sample Test (Normal Approximation).

Variable	F Value	P>F	$\chi^2$	P> $\chi^2$
Total	19.513	0.0001	53.919	0.0001
Without <i>W.</i>	12.647	0.0001	16.985	0.0002

Variable	F Value	P>F	Z	P> Z
Total	13.149	0.0005	-3.31978	0.0009
Without <i>W.</i>	0.046	0.8307	-0.13953	0.8890

normally distributed after their transformation. The dispersal index  $B=s^2/m$  (where  $s^2$  is the variance and  $m$  is the mean; Cancela da Fonseca, 1966) was calculated for each site and for each family sampled. Aggregative distribution ( $B>1$ ) was tested by T-test.

## RESULTS

#### ARTHIPOD DENSITY & LOCAL DISTRIBUTION

The densities of arthropods was 1374, 545 and 281 ind./m<sup>2</sup> in Païta, Pindaï and Rivière Bleue, respectively.

The forests in Païta and Pindaï have been invaded by the neotropical ant *Wasmannia auropunctata* (Roger) which constituted 65% and 15% of the specimens collected in Païta and Pindaï, respectively. After removing the invader from the samples, the mean abundances of arthropods in both sclerophyllous forests were found quite similar (Table 2), while a much lower abundance was still noticeable in Rivière Bleue. Subsequent analysis of abundance patterns exclude *W. auropunctata*.

Dispersal indices tested by T-tests show that 49% and 36% of the families in the sclerophyllous forests of Pindaï and in Païta, respectively, are distributed in aggregats; whereas only 18% of the families exhibit such a distribution in the rainforest of Rivière Bleue.

#### ABUNDANCE PATTERNS

We found 54974, 21815 and 11260 specimens in Païta, Pindaï and Rivière Bleue, respectively. At order level, the three sites differed by their abundance patterns, but the 2 sclerophyllous forests were more similar to each other than to the rainforest (Table 3). In proportion to the total number of specimens collected in each site,

Orders	F Value	P>F	Z	P> Z
Diptera	7.183	0.0011	8.6865	0.0130
Lepidoptera	23.558	0.0001	47.011	0.0001
Hymenoptera	20.152	0.0001	88.577	0.0001
Neuroptera	19.808	0.0001	37.980	0.0001
Megaloptera	3.265	0.0417	10.041	0.0066
Coleoptera	9.111	0.0002	37.095	0.0001
Hemiptera	29.231	0.0001	61.704	0.0001
Thysanoptera	25.192	0.0001	44.199	0.0001
Psocoptera	34.061	0.0001	80.214	0.0001
Dictyoptera	28.490	0.0001	40.006	0.0001
Dermaptera	1.000	0.3710	2.0000	0.3679
Orthoptera	3.639	0.0293	20.884	0.0001
Phasmoda	3.743	0.0256	7.3392	0.0255
Embiopiera	2.053	0.1330	4.0339	0.1331
Ephemeroptera	2.053	0.1330	4.0339	0.1331
Thysanura	7.384	0.0010	21.584	0.0001
Collembola	76.042	0.0001	87.335	0.0001
Araneae	44.493	0.0001	69.575	0.0001
Pseudoscorpionida	16.669	0.0001	41.737	0.0001
Acari	13.595	0.0001	22.399	0.0001
Chilopoda	1.022	0.3629	2.0517	0.3585
Amphipoda	1.000	0.3710	2.0000	0.3679
Isopoda	2.634	0.0760	5.4065	0.0670

Orders	F Value	P>F	Z	P> Z
Diptera	10.726	0.0016	-2.83456	0.0046
Lepidoptera	4.269	0.0421	1.96942	0.0489
Hymenoptera	17.918	0.0001	-6.37994	0.0001
Neuroptera	0.857	0.3576	0.270453	0.7868
Megaloptera	1.846	0.1781	-2.19185	0.0284
Coleoptera	12.988	0.0005	4.21338	0.0001
Hemiptera	7.535	0.0075	1.81420	0.0696
Thysanoptera	3.423	0.0681	-2.07431	0.0381
Psocoptera	1.775	0.1867	-1.54457	0.1225
Dictyoptera	15.591	0.0002	-2.63687	0.0084
Dermaptera				
Orthoptera	1.157	0.2853	0.280304	0.7792
Phasmoda	4.944	0.0291	2.28269	0.0224
Embiopiera	2.053	0.1559	-1.40546	0.1599
Ephemeroptera				
Thysanura	7.384	0.0081	3.34149	0.0008
Collembola	15.846	0.0002	5.15598	0.0001
Araneae	4.660	0.0340	1.61213	0.1069
Pseudoscorpionida	21.751	0.0001	6.16767	0.0001
Acari	19.898	0.0001	-3.97507	0.0001
Chilopoda	1.838	0.1791	1.40535	0.1599
Amphipoda				
Isopoda	4.944	0.0291	2.28269	0.0224

Table 3 a, b. Comparison of mean abundance of prevalent orders and classes.

a. Comparison for the 3 sites by Kruskal-Wallis Test (Chi-Square Approximation, Df=2)

b. Comparison for the 2 sclerophyllous forests by Wilcoxon 2-Sample Test (Normal Approximation).

Psocoptera were abundant and Collembola were scarce in both sclerophyllous forests (fig. 1); whereas Diptera Nematocera and Acarina were more numerous while Hemiptera and Thysanoptera were relatively scarce in Rivière Bleue. The Païta site differed from the two others by high proportions of larvae (42% Lepidoptera, 42% Coleoptera, total 14% vs. c. 0%), and low proportion of adult Coleoptera (2.8% vs. c. 12%).

Theridiidae were the prevalent Araneae everywhere and were particularly abundant in the sclerophyllous forests (Table 4). In the Rivière Bleue rainforest, Clubionidae were almost as numerous as Theridiidae. Other important araneid families were Uloboridae in Païta, Philodromidae in Pindaï, Salicidae in Rivière Bleue. Among Coleoptera, Curculionidae were numerous everywhere. Other dominant groups were Ciidae and Cerambycidae in Païta, Phalacridae in Pindaï, Staphylinidae in Rivière Bleue. Cicadellidae were the prevalent Hemip-

tera in both sclerophyllous forests but not in Rivière Bleue. The dominant Heteroptera were Tingidae in Pindaï, Miridae in Rivière Bleue. Formicidae were the prevalent Hymenoptera in sclerophyllous forests even after exclusion of *W. auripunctata*. Other abundant groups were Braconidae in Païta and Encyrtidae in Pindaï. Chironomidae and Ceratopogonidae were the most numerous dipteran Nematocera everywhere. Cecidomyiidae and Sciaridae were also noticeably abundant in Païta and Rivière Bleue while a better balance between dipteran families was observed in Pindaï. In dipteran Brachycera, the relative abundance of Chloropidae was consistent in all sites. Muscidae were important only in Pindaï, Lauxaniidae only in Païta. Drosophilidae and Dolichopodidae were scarce in Pindaï.

The Païta sample lacked Pseudoscorpiones (present in Pindaï), Isopoda and Diplopoda. Thysanura were found only in Pindaï, Opiliones



Guilds	F Value	P > F	Z	P >  Z
Chewers	9.774	0.0001	25.714	0.0001
Suckers	21.252	0.0001	-47.083	0.0001
Scavengers	5.169	0.0071	14.494	0.0007
Ants	20.114	0.0001	84.423	0.0001
Parasitoids	16.467	0.0001	27.381	0.0001
Tourists	4.486	0.0133	5.8654	0.0533
Epiphyte grazers	6.186	0.0028	5.4969	0.0040
Insect predators	9.628	0.0001	13.655	0.0011
Other Predators	10.979	0.0001	19.150	0.0001
Uncertains	14.202	0.0001	34.563	0.0001

Guilds	F Value	P > F	Z	P >  Z
Chewers	2.878	0.0938	1.59389	0.1110
Suckers	29.061	0.0001	4.53624	0.0001
Scavengers	5.994	0.0166	0.337116	0.7360
Ants	13.023	0.0005	5.62373	0.0001
Parasitoids	29.770	0.0001	4.55101	0.0001
Tourists	3.855	0.0532	-1.91552	0.0554
Epiphyte grazers	7.748	0.0067	1.47248	0.1409
Insect predators	5.378	0.0230	0.892044	0.3724
Other Predators	13.271	0.0005	2.95970	0.0031
Uncertains	16.755	0.0001	5.54159	0.0001

Table IV a,b. Comparison of mean abundance of trophic guilds.

a. Comparison for the 3 sites by Kruskal-Wallis Test (Chi-Square Approximation).

(1 specimen) and Dermaptera only in Rivière Bleue. Each site lacked some families.

In proportion, ants were found more important in sclerophyllous forests, and constituted the dominant guild in Païta. Their abundance in Païta was so much greater that overall the abundances of the trophic guilds were found more similar between Rivière Bleue (rainforest) and Pindaï (sclerophyllous forest) than between the 2 sclerophyllous forests (Table IV). Without considering *W. auropunctata*, the 3 New Caledonian forests show similar proportions among the trophic guilds (Fig. 2). They are characterized by the prevalence of non-insect predators, mostly Araneae and epiphyte grazers. Tourists (mostly Diptera) were more abundant in Rivière Bleue forest than in sclerophyllous forests, but the difference between the 3 sites was not found significant when tested by Kruskal-Wallis test. The relative abundance of chewers and suckers is very low in the New Caledonian forests, especially in Rivière Bleue.

## DISCUSSION

### IMPLEMENTATION, STRENGTHS & WEAKNESSES OF THE METHOD

The choice of fogging an area rather than a single species of tree was pragmatic: isolating a tree in New Caledonian forests implies extensive destruction. In addition, one may notice that in these forests the canopy of each tree is not spatially distinct, but rather is intimately intricate with the ones of surrounding trees; consequently, sampling an area rather than one tree may, in such forests, be representative of the ecological reality.

b. Comparison for Pindaï and Rivière Bleue forests by Wilcoxon 2-Sample Test (Normal Approximation).

Using many small standard collectors rather than a few large ones allows limited destruction of the lower vegetation and induces less disturbance in the biotop. Furthermore, it provides area-related data which allow analysis of spatial distribution and facilitate comparisons at various levels. As implemented here, fogging can be used by a reduced staff of 2 operators. Operators can sample from ground level, in vegetation up to 25 m in best weather conditions (still air, no rain). Small and fragile arthropods are collected in good condition for taxonomical studies. Good flyers (even of large body size: Macrolepidoptera, Cicadidae...) are sampled when fogging takes place at dawn before they can readily fly away.

In this implementation, the fogging method gives poor information on sampled vegetal volume and no information on faunal stratification. Sampling vegetation strates should be more informative than plain fogging, as a large proportion of the species which visit the canopy don't feed in it (Stork, 1991). Furthermore, the fogging method cannot be used by windy or rainy day. It is unable to sample arthropods which migrate from the ground to the canopy during the day, arthropods hidden under bark and most nocturnal arthropods. We also suppose that strong fliers would not be correctly sampled throughout the day.

### COMPARISON OF THE SITES

Because *W. auropunctata* occurs in sclerophyllous forests, Rivière Bleue forest has the lowest total numbers of specimens /m<sup>2</sup>. It differs also from both sclerophyllous forests by higher relative abundance of Collembola, Acarina,

Appendix. Relative abundance of taxa (% of ind. in prevalent orders).

	Païta	Pindai	RBléue
<b>Araneae</b>			
Araneidae	6.7	3.2	3.6
Clubionidae	13.8	25.0	30.6
Gnaphosidae	2.1	0.3	0.0
Linyphidae	0.5	0.2	6.8
Oonopidae	3.8	3.9	8.3
Philodromiidae	0.4	13.2	0.0
Salticidae	1.3	2.2	12.5
Tetragnathidae	1.2	0.4	0.5
Theridiidae	56.7	47.3	32.2
Thomisidae	1.2	2.7	1.8
Uloboridae	12.4	0.3	1.0
Others	0.1	1.4	2.6
	100	100	100
<b>Coleoptera</b>			
Aderidae	2.3	0.0	2.4
Anthribidae	2.3	2.4	0.8
Attelabidae	0.0	4.7	0.0
Byrrhidae	4.8	0.0	3.8
Cebrionidae	0.0	1.2	0.0
Cerambycidae	14.9	4.7	0.8
Chrysomelidae	2.7	7.4	4.3
Ciidae	27.1	1.6	1.0
Coccinellidae	7.8	8.9	3.8
Colydiidae	0.8	0.6	1.5
Corylophidae	0.6	7.2	5.0
Cryptophagidae	0.0	3.1	1.9
Cucujidae	1.8	0.6	2.0
Curculionidae	21.0	16.5	32.5
Lathrididae	2.7	5.6	1.1
Melandryidae	0.0	0.0	2.4
Merophysiidae	0.2	0.0	4.6
Nitidulidae	0.3	6.4	0.0
Phalacridae	0.0	20.9	0.7
Pselaphidae	1.6	0.6	7.9
Scolytidae	2.1	4.0	4.2
Staphylinidae	4.2	2.0	17.5
Others	2.7	1.4	1.8
	100	100	100
<b>Hemiptera</b>			
Aleyrodidae	1.0	0.5	2.5
Anthocoridae	0.8	2.9	3.1
Aphididae	3.4	0.0	0.3
Aradidae	3.4	1.1	3.1
Cicadellidae	40.4	40.6	8.1

	Païta	Pindai	RBléue
Delphacidae	8.6	3.3	4.5
Fulgoridae	0.0	1.6	6.4
Lygaeidae	4.4	0.8	2.5
Margarodidae	0.7	0.7	0.0
Miridae	1.6	2.7	11.7
Pentatomidae	0.4	1.2	0.0
Psyllidae	1.3	13.1	13.1
Reduviidae	4.3	1.5	1.4
Tingidae	2.4	11.9	10.1
Homoptera larvae	17.4	2.9	7.3
Heteroptera larvae	6.8	14.3	13.1
Others	3.2	1.1	12.8
	100	100	100
<b>Diptera</b>			
<b>Nematocera</b>			
Cecidomyiidae	14.6	6.2	17.4
Ceratopogonidae	36.9	30.7	36.9
Chironomidae	25.5	48.7	30.8
Mycetophilidae	0.9	1.1	0.2
Psychodidae	5.5	0.3	0.9
Sciaridae	16.0	7.6	11.8
Tipulidae	0.6	5.1	1.5
Others	0.0	0.2	0.5
	100	100	100
<b>Brachycera</b>			
Chloropidae	33.0	37.2	44.0
Dolichopodidae	10.8	2.1	7.3
Drosophilidae	13.6	1.3	13.6
Empididae	0.2	5.0	13.9
Lauxaniidae	22.8	8.4	9.7
Mrichnidae	0.2	0.4	3.1
Muscidae	7.0	15.9	1.6
Phoridae	6.1	6.3	1.0
Sarcophagidae	0.9	4.2	0.0
Tachinidae	1.9	4.6	0.3
Tephritidae	1.0	8.4	1.8
Others	2.6	6.3	3.7
	100	100	100
<b>Hymenoptera (excl. <i>W. auropunctata</i>)</b>			
Agaonidae	6.6	0.0	0.1
Aphelinidae	11.9	9.2	22.0
Braconidae	16.4	4.0	7.5
Ceraphronidae	1.4	0.7	1.5
Cleptidae	0.8	1.7	1.2
Encyrtidae	7.4	17.5	7.6
Eulophidae	13.6	5.5	11.2
Eupelmidae	1.2	0.6	0.0

## Appendix (continued)

	Païta	Pindai	R. Bleue
Hymenoptera (excl. <i>W. auropunctata</i> )			
Formicidae	18.2	23.5	19.5
Ichneumonidae	1.9	1.2	0.8
Mymaridae	5.5	5.7	6.4
Platygasteridae	6.9	3.4	11.1
Pteromalidae	1.1	4.7	3.0
Secionidae	4.8	10.9	5.0
Sphecidae	0.0	4.3	0.0
Torymidae	0.6	0.8	0.4
Trichogrammatidae	0.6	2.2	0.7
Others	1.3	1.0	1.9
	100	100	100

Nematocera, Aphelinidae, Tingidae, Curculionidae, Staphylinidae and by relative scarcity of Araneae, Psocoptera, Thysanoptera and Hemiptera, especially Cicadellidae. The prevalence of Chironomidae and Ceratopogonidae in Rivière Bleue might be related to the vicinity of the river banks, but the absence of permanent streams excludes such explanation in Païta and in Pindai sclerophyllous forests. Aggregative patterns seem more common in sclerophyllous forests, which could be attributed to greater physical heterogeneity of the canopy. In spite of their overall similarity, sclerophyllous forests display some differences: some may be explained by floristic composition (Agaonidae which are related to presence of *Ficus* in Païta; Jaffré & Veillon, pers. comm.) or by microclimatic conditions (fungal eaters Lauxaniidae are less abundant in the drier forest of Pindai). Selective predation may also be involved. Further analysis is required to verify the persistence of such differences and similarities throughout the year.

Ants are generally abundant in tropical canopies, which is the case only in our samples from sclerophyllous forests (Païta in particular) (Fig. 2), seemingly owing to the introduction of *Wasmannia auropunctata*. The dominance of these introduced ants in Païta is associated with scarcity of epiphyte grazers (Table 4), as observed by Grant & Moran (1986) from their South African samples. The scarcity of non-introduced ants resembles the pattern observed in *Argyrodendron* canopy in Queensland (Basset & Arthington, 1992). This scarcity has been hypothesized to be the result of a lesser productivity (Majer, 1990). Here dry season water stress could explain the difference between Pindai

(drier) and Païta (wetter). However, such an explanation cannot be applied to the pattern observed in the evergreen forest of Rivière Bleue.

Prevalence of non-insect predators, mostly Araneae and epiphyte grazers as observed in the three New Caledonian forests, is characteristic of temperate forests rather than of tropical ones (Basset & Arthington, 1992). The high proportion of 'tourists' observed in Rivière Bleue forest could be due to the higher rainfall and the vicinity of the river banks.

More differences should obviously be observed between sites at genus and species level. For example, Coccinellidae are represented by 9 genera and 12 species in Païta, 8 species and 7 genera in Pindai, 4 genera and 5 species in Rivière Bleue. Païta and Pindai have 2 genera and 2 species in common: 1 species is endemic, the other was introduced recently.

When compared with results obtained in Queensland (Kitching et al., 1993), the Rivière Bleue sample is found quite similar to tropical samples from the 'Green Mountains' (Kitching et al., 1993); differences are found principally in the proportions of Collembola and Acari. The two New Caledonian sclerophyllous forests samples are more similar to the subtropical samples from the 'Green Mountains', except for the relative abundance of Collembola which is weaker in New Caledonian samples.

## ANTHROPIC AGGRESSION &amp; INVASION OF BIOTAS

*W. auropunctata* has been recorded in New Caledonia since 1972 (Fabres & Brown, 1978). Its introduction and the rapid invasion of coastal lowlands is attributed to human activity. Open areas and bush fires benefit the invader. Relictual forests like Païta (surrounded by pastures and *Melaleuca* savanas) and Pindai (surrounded by frequently burnt *Acacia spirorbis* woodlands) are more exposed to invasion. The relative isolation of the dense evergreen forest, as well as its ecological characteristics, may have prevented or delayed the arrival of the ant.

At this stage we cannot ascertain the reason for depletion in specific richness in the invaded forests. Interference competition of *W. auropunctata* may have displaced other ants and spiders as observed elsewhere (Pollard & Persad, 1991). Hence important changes in faunal equilibrium may be expected in invaded areas. Subsequent sampling will refine that point.

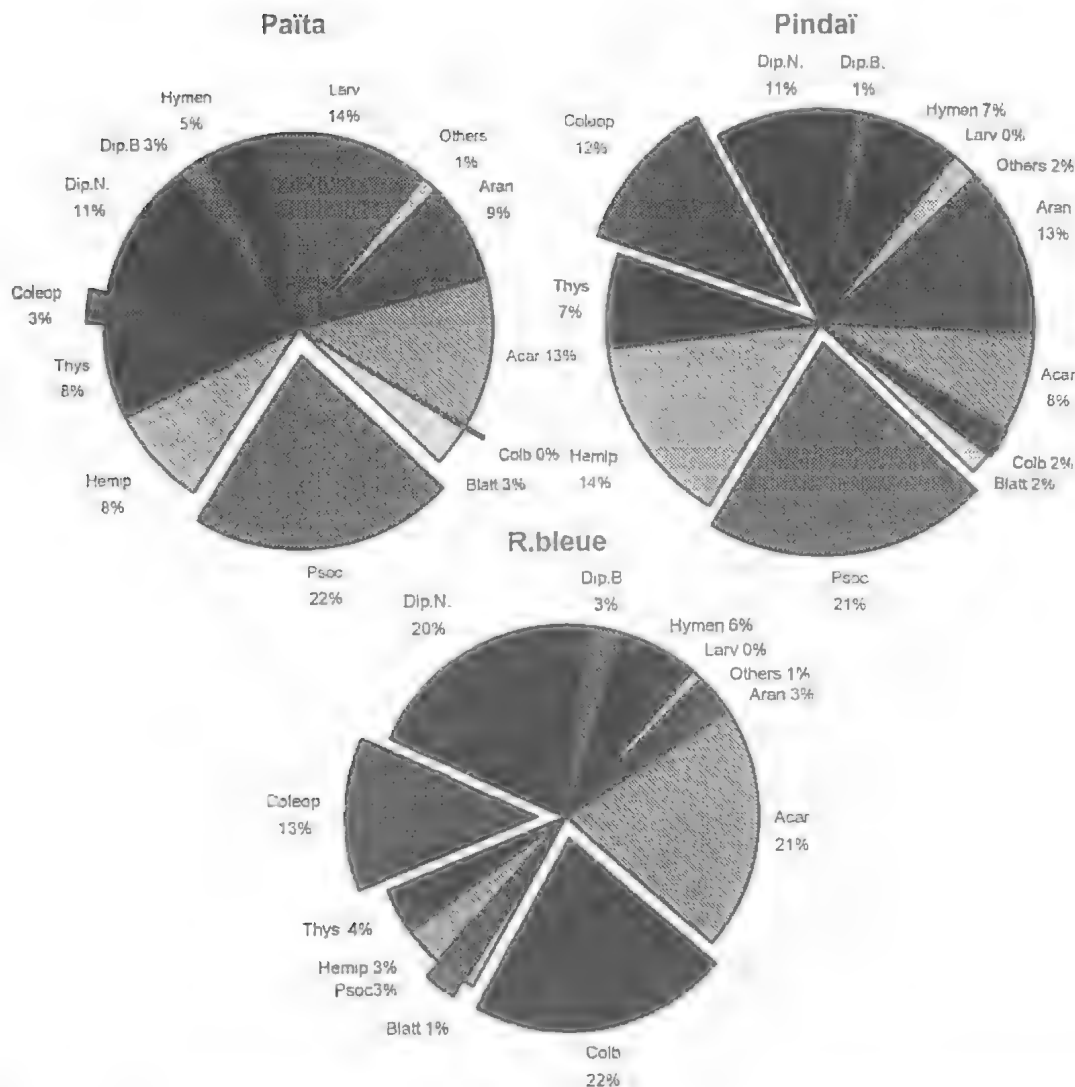


Fig. 1. Relative abundance of prevalent groups. Aran., Araneae; Acar., Acarina; Colb., Collembola; Blatt., Blattodea; Psoc., Psocoptera; Hemip., Hemiptera; Thys., Thysanoptera; Coleop., Coleoptera; Dip.N., Diptera Nematocera; Dip.B., Diptera Brachycera; Hymen., Hymenoptera (excluding *W. auronitens*), Larv., Insect larvae.

## CONCLUSION

Sorting to family level a single sample of each of our sites allowed distinction between the sites, and indicates that probably larger New Caledonian forest types may be characterized using this technique. However, understanding diversity requires more than defining the taxonomic structure of communities at one time. Seasonal changes may affect the proportions of the different taxa, including the presence or ab-

sence of some of them. The use of small standard collecting units throughout one year should allow analysis of the distribution of taxa through time and space, and will provide a test for the efficiency of the method: have we undersampled the area? Is our sample 'representative' of the biotope? Another question is the taxonomic level of the analysis—family level allows rapid results, but is obviously far less precise than specific level. How is the relationship between these two levels in terms of diversity and of community

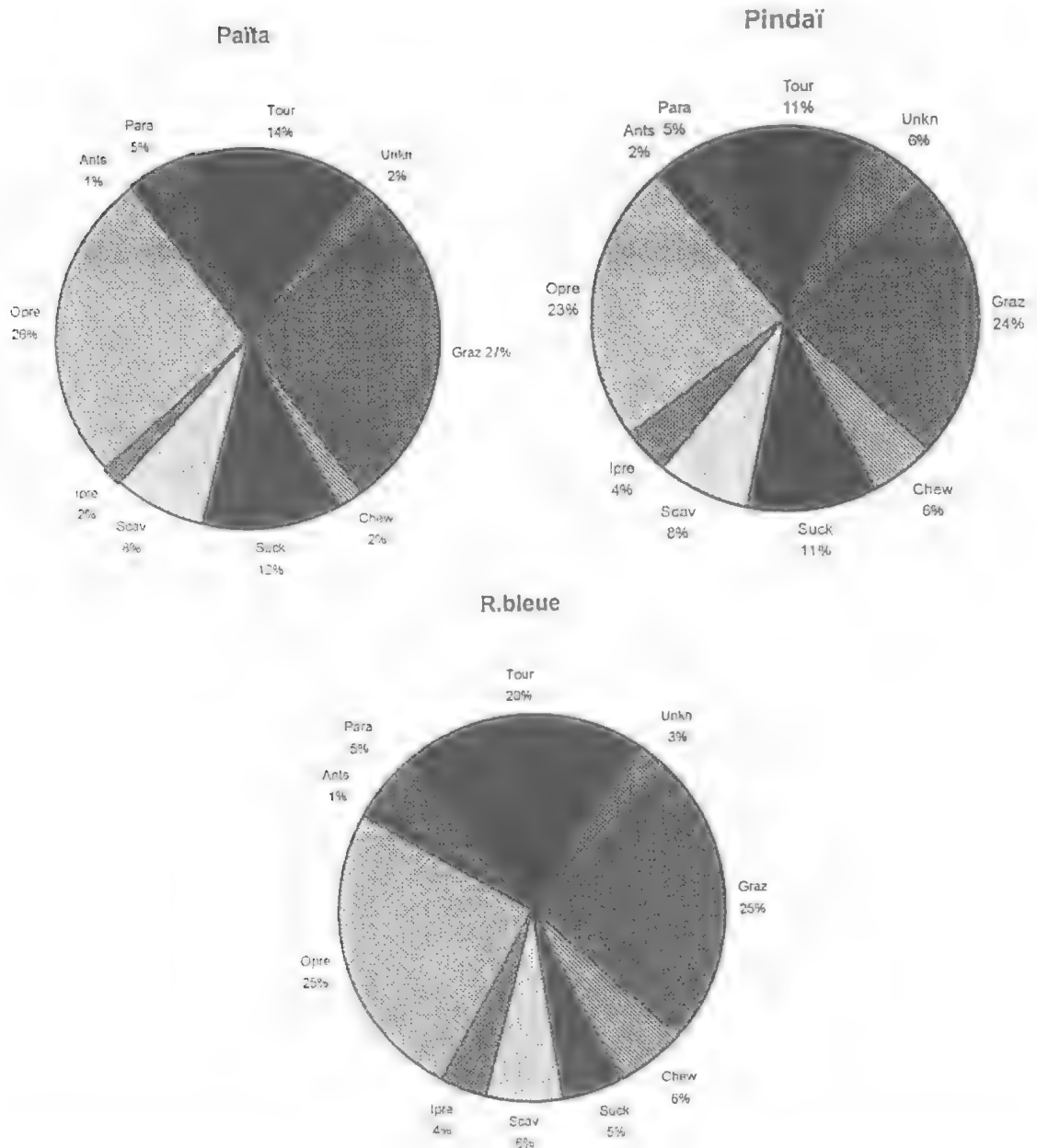


Fig 2. Relative abundance of trophic guilds. Abbreviations: Graz, Epiphyte grazers; Chew, Chewers; Suck, Suckers; Scav, Scavengers; Ipre, Insect predators; Opre, Other predators; Ants, Ants (excluding *W. auropunctata*); Para, Parasitoids; Tour, Tourists; Unkn, Unknown.

structure? Does one level show more spatial and temporal stability than the other?

For ecological analysis, clearly the use of other methods of sampling and life history studies should complement fogging. The scientific value

of data on identified host plants, related faunas and their stratification is beyond all question. Although the fogging method is relatively weighty, it constitutes a fast global approach of biota which might provide the information we

most urgently need to promote conservation of ecologically sensitive forested areas.

### ACKNOWLEDGMENTS

This work is part of the programs 'Biodiversité terrestre en Nouvelle-Calédonie' (DRED/Museum) and 'Caractérisation des peuplements des forêts et maquis non anthropisés' (ORSTOM). The authors thank T. Jaffré, J.-M. Veillon and F. Rigault, ORSTOM New Caledonia, who provided botanical informations, and Y. Basset, R. Raven and S. Tillier for their comments on the manuscript.

### LITERATURE CITED

- BASSET, Y. 1991. The taxonomic composition of the arthropod fauna associated with an Australian rainforest tree. *Australian Journal of Zoology* 39: 171-190.
- BASSET, Y. & ARTHINGTON, A.H. 1992. The arthropod community of an Australian rainforest tree: abundance of component taxa, species richness and guild structure. *Australian Journal of Ecology* 17: 89-98.
- BONNET DE LARBOGNE, L., CHAZEAU, J., TILLIER, A. & TILLIER, S. 1991. Milieux naturels néo-calédoniens: la Réserve de la Rivière Bleue. *Mémoires du Muséum national d'Histoire naturelle (Zoologie)* 149: 9-17.
- CANCELA DA FONSECA, J.P. 1966. L'outil statistique en biologie du sol III, Indices d'intérêt écologique. *Revue d'Ecologie et de Biologie du Sol* 3: 381-407.
- CHAZEAU, J. & TILLIER, S. 1991. *Zoologia Neocaledonica*, 2. *Mémoires du Muséum National d'Histoire Naturelle, Série A (Zoologie)*, 149. Pp. 358.
- ERWIN, T.L. 1982. Tropical forests: Their richness in Coleoptera and other species. *Coleopterists Bulletin* 36: 74-75.
1983. Beetles and other insects of tropical forest canopies at Manaus, Brazil, sampled by insecticidal fogging. Pp. 59-79. In Sutton, S.L. & al. (eds), 'Tropical rainforest ecology and management'. (Blackwell: Oxford).
- FABRES, G. & BROWN, W.L. 1978. The recent introduction of the pest ant *Wasmannia auropunctata* into New Caledonia. *Journal of the Australian entomological Society* 17: 139-142.
- GRANT, S. & MORAN, V.C. 1986. The effects of foraging ants on arboreal insect herbivores in an undisturbed woodland savanna. *Ecological Entomology* 11: 83-93.
- JAFFRÉ, T., MORAT, P. & VEILLON, J.-M. 1993. Etude floristique et phytogéographique de la forêt sclérophylle de Nouvelle-Calédonie. La forêt sclérophylle de la Province Sud de la Nouvelle-Calédonie. *Adansonia* 15 (1-4): 107-146.
- JAFFRÉ, T. & VEILLON, J.-M. 1991. Etude floristique et structurale de deux forêts dense humides sur roches ultrabasiques en Nouvelle-Calédonie. *Adansonia* 12 (3-4): 243-273.
- KITCHING, R.L., BERGELSON, L.M., LOWMAN, M.D., MCINTYRE, S. & CARRUTHERS, G. 1993. The biodiversity of arthropods from Australian rainforest canopies: general introduction, methods, sites and ordinal results. *Australian Journal of Ecology* 18: 181-191.
- MAJER, J.D. 1990. The abundance and diversity of arboreal ants in northern Australia. *Biotropica* 22: 191-199.
- MARTIN, J.L. 1966. The insect ecology of red pine plantations in central Ontario. IV. The crown fauna. *Canadian Entomologist* 98:10-27.
- MATILE, L., NAJT, J. & S. TILLIER (eds.) 1993. *Zoologia Neocaledonica*, 3. *Mémoires du Muséum National d'Histoire Naturelle, Série A (Zoologie)*, 157. Pp. 218.
- MAY, R.M. 1990. How many species? *Philosophical Transactions of the Royal Society of London* 330. 293-304.
- MORAN, V.C. & SOUTHWOOD, T.R.E. 1982. The guild composition of arthropod communities in trees. *Journal of Animal Ecology* 51: 289-306.
- MYERS, N. 1988. Threatened biotas: "hot spots" in tropical forests. *The environmentalist* 8 (3): 187-208.
- POLLARD, G.V. & PERSAD, A.B. 1991. Some ant predators of insect pests of tree crops in the Caribbean with particular reference to the interaction of *Wasmannia auropunctata* and the leucaena psyllid *Heteropsylla cubana*. Pp. 392-403. In 'Rencontres Caraïbes en Lutte biologique', INRA, Paris, Les Colloques, 58.
- ROBERTS, H.F. 1973. Arboreal Orthoptera in the rain forest of Costa Rica collected with insecticide: a report of the grasshoppers (Acrididae) including new species. *Proceedings of the Academy of Natural Science of Philadelphia* 125: 46-66.
- STORK, N.E. 1987. Guild structure of arthropods from Bornean rain forest trees. *Ecological Entomology* 12: 69-80.
1988. Insect diversity: facts, fiction and speculation. *Biological Journal of the Linnean Society* 35: 321-337.
1991. The composition of the arthropod fauna of Bornean lowland forest trees. *Journal of tropical Ecology* 7: 161-180.
- TILLIER, S. 1988. *Zoologia Neocaledonica*, 1. *Mémoires du Muséum National d'Histoire Naturelle, Série A (Zoologie)*, 142. Pp. 158.



## THE EFFECTS OF DEVELOPMENT ON FIJIAN ISLAND FRESHWATER INVERTEBRATES

ALISON HAYNES

Haynes, A. 1994 06 30: The effects of development on Fijian island freshwater invertebrates. *Memoirs of the Queensland Museum* 36(1): 87-91. Brisbane. ISSN 0079-8835.

The invertebrate fauna of tropical Pacific streams is composed mainly of gastropods and shrimps. Insect larvae and nymphs are a relatively small part of the invertebrate biomass. The streams are subject to flooding and siltation after logging and road making. This results in depletion of invertebrate populations. Some of the less abundant species might never recolonize impoverished, isolated streams. The lake formed by the building of the Monasavu Hydroelectric dam on Viti Levu, Fiji, has fewer invertebrates than the flooded Nanuku creek. The gastropod *Viviparus japonicus*, which was accidentally introduced with prawns for aquaculture, has become a serious problem in a fish hatchery; it is only a matter of time before the snail becomes established in a nearby river. The invertebrate fauna is being impoverished and changed by development. □ Freshwater, invertebrates, Mollusca, Crustacea, Insecta, introductions, Pacific islands, Viti Levu, Fiji, hydroelectric dam, logging, siltation.

Alison Haynes, School of Pure and Applied Sciences, University of the South Pacific, PO Box 1168, Suva, Fiji; 10 August 1993.

Streams and rivers of Pacific Islands, which often flow in channels cut in steep hillsides, have relatively diverse invertebrate faunas. They are especially rich in shrimp and gastropod species. These insular, freshwater communities have evolved in isolation and are liable to be upset by introductions and changes caused by developments such as logging of forests, road making, the building of dams, and forest clearing for large-scale farming.

It has been argued that because Pacific island

streams are prone to natural disasters such as cyclones, floods and landslides, the species that have become established are the only ones that can survive there. This notion, however, is contradicted by the abundance of introduced Cane Toads (*Bufo marinus*) and the presence of the East African thiarid snail, *Melanoides tuberculata*, on nearly all Pacific islands (Haynes, 1990).

The purpose of this paper is to present instances where development of various kinds has affected invertebrate species diversity and abundance. The examples are mainly from Fiji, one of the most developed Pacific Island countries.

### THE EFFECT OF THE MONASAVU DAM

The Monasavu hydroelectric dam was constructed at an altitude of 750m in the headwaters of the Rewa river on Viti Levu, Fiji between 1977-1982 (Fig. 1). It was made of loose rocks at a site upstream from the original Monasavu falls (Fig. 2). The Nanuku valley and stream were similar to others in the inland highlands of Viti Levu. Rainforest that covered its slopes was left standing when the valley was flooded.

Before the dam's construction in April-May 1977, invertebrates were sampled just above the Monasavu falls (INR, 1977). In 1982 while the reservoir was filling, invertebrates were again sampled near the end of the construction road



FIG. 1. Monasavu area, Viti Levu, Fiji.



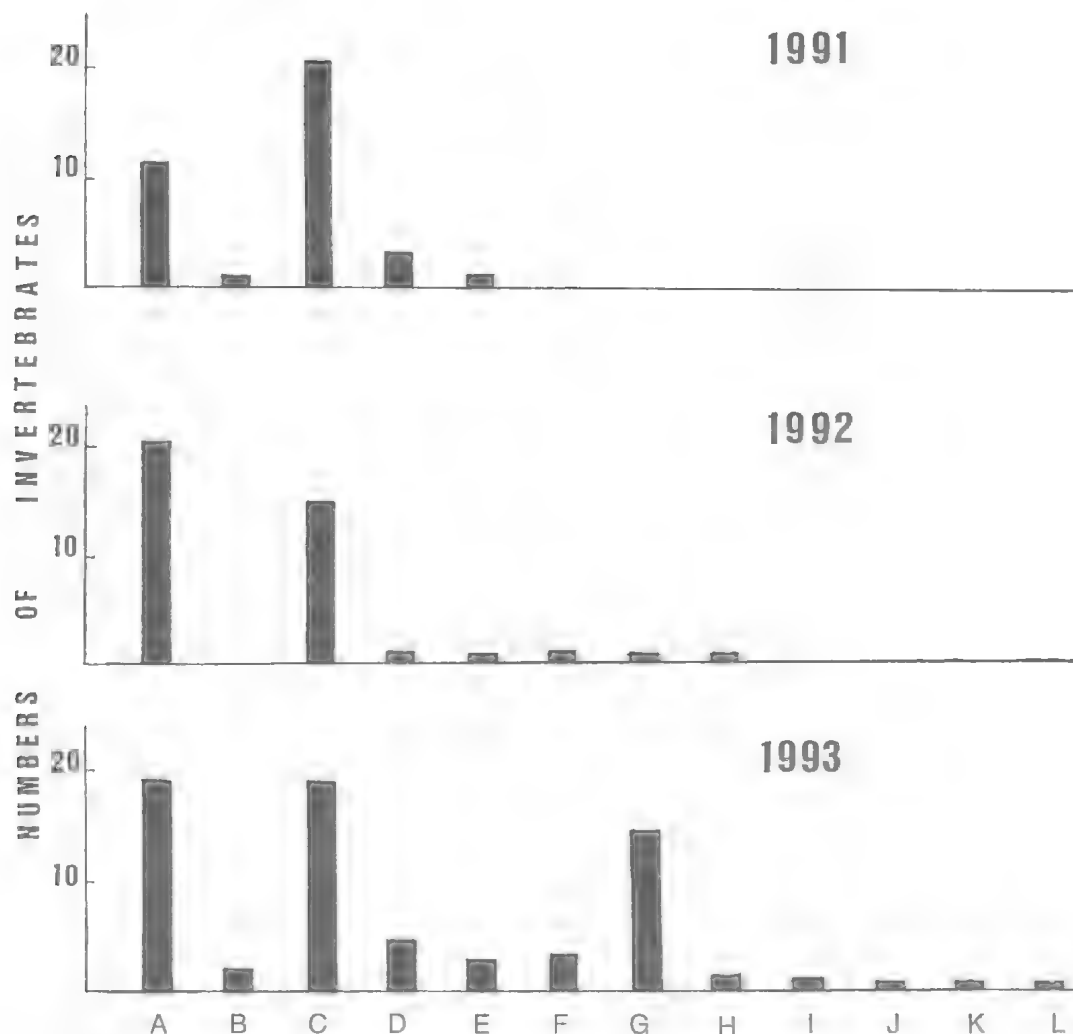


FIG. 3. The number of benthic invertebrates in the Nabukavesi creek in 1991-93: A = net caddis larvae; B = net caddis pupae; C = mayfly swimmer nymph; D = mayfly clinger nymph; E = moth larvae; F = stony-cased caddis fly larvae; G = simuliid larvae; H = damselfly nymph; I = atyid shrimps; J = secreted-cased caddis larvae; K = gastropod *Melanoides tuberculata*; L = oligochaete worm.

after most of the mud had been washed away. By 1993, 12 different species were established at the site showing that fast flowing streams do recover after sedimentation. More species of damselfly nymphs (3) and atyid shrimps (3), however, were found in the nearby Wainikovu creek where no logging had occurred.

#### THE INTRODUCTION OF EXOTIC SPECIES

Various species of *Tilapia*, carp and shrimps

(*Macrobrachium*) have been introduced into Fiji and other island countries for aquaculture. In Fiji they are bred and kept until wanted at the Fisheries Department fish hatcheries at Naduruloulou. The shrimps and fish are given to villages that have suitable ponds for culture. So far they do not appear to have affected the indigenous fauna. However, the gastropod *Viviparus japonicus* was inadvertently introduced into the fish ponds on vegetation accompanying the *Macrobrachium* from Japan. They

TABLE 1. Invertebrates found in the Nanuku creek and Lake Monasavu after the dam was built and the valley flooded.

Invertebrates	Nanuku creek	Lake filling		Lake	Monasavu	
	1977	1982	1985	1987	1989	1990
MOLLUSCA						
<i>Melanoides tuberculata</i>	*			*	*	*
<i>Physastra nasuta</i>	*	*	*	*		*
<i>Fluviopupa pupoides</i>	*			*		
<i>Ferrissia noumeensis</i>			*			
OTHER						
leech	*	*	*	*		*
planarian	*	*		*		*
mayfly nymphs	*					
damselflies nymphs	*	*		*	*	
dragonfly nymphs	*	*		*	*	
beetle larvae	*	*				
caddis fly larvae	4 spp.			1 sp.	2 spp.	1 sp.
simuliid larvae	*					
moth larvae	*					
crickets	*				*	
back swimmers	*					
water striders	*					
mosquito larvae		*				
bryozoans			*			
palaeomonid shrimps	*					
green sponge				*		*

were first noticed in April 1989. By April 1991, *V. japonicus* were so numerous that they clogged two fish ponds and made them inoperable. It is only a matter of time before the gastropods reach the nearby Rewa river. Their effect on the local fauna is yet to be discovered.

## DISCUSSION

The building of a dam and the impounding of a stream wiped out a whole natural community at Monasavu. Few species were found in the lake 3 years after it was filled with water, probably due to rotting vegetation producing  $H_2S$  and depressing the dissolved oxygen content of the water (INR, 1987). More species returned as decomposition of vegetation decreased but disappeared

when the water level fell 20m in 1991 (Table 1).

Invertebrate species are often transient in a stream because the stream is liable to flooding during heavy rain and to siltation when hillsides are eroded after they have been cleared for farming, road building or during the logging of forests. Some of the less abundant species might be lost if they are in remote streams. The more isolated the stream the less likely it is to be recolonized (Haynes, 1990).

Many freshwater invertebrate species are widely distributed throughout islands in the Pacific but research on the islands of Fiji and French Polynesia (Resh et al., 1990) has revealed species with limited distribution. In Fiji, the gastropod *Fijidoma maculata* (Haynes, 1988) and three species of the shrimp *Caridina* (Choy,

1991) are restricted to Viti Levu while the gastropods *Fluviopupa pupoidea* (Haynes, 1985) and *Acochlidium fijiensis* (Haynes & Kenchington, 1991) are found only on Viti Levu and Vanua Levu.

Probably endemic species of stream insects also exist in Fiji but the results of development might drive them to extinction before they are discovered and described.

#### ACKNOWLEDGEMENTS

I wish to thank the University of the South Pacific Research Committee and the Institute of Applied Sciences, USP for making this work possible.

#### LITERATURE CITED

- CHOY, S.C. 1991. The atyid shrimps of Fiji with a description of a new species. *Zoologische Mededelingen* 65: 343-361.
- HAYNES, A. 1985. The ecology and local distribution of non-marine aquatic gastropods in Viti Levu, Fiji. *The Veliger* 28 (2): 204-210.
1988. A population study of the Fijian freshwater thiarid gastropod *Fijidoma maculata* (Mousson). *Archiv für Hydrobiologie* 113(1): 27-39.
1990. The numbers of freshwater gastropods on Pacific islands and the theory of island biogeography. *Malacologia* 31(2): 237-248.
- HAYNES, A. & KENCHINGTON, W. 1991. *Acochlidium fijiensis* sp. nov. (Gastropoda: Opisthobranchia: Acochliidae) from Fiji. *The Veliger* 34(2): 166-171.
- INR (INSTITUTE OF NATURAL RESOURCES) 1977. 'Report on biological studies conducted in the area around the proposed Monasavu hydroelectric dam.' (University of the South Pacific: Suva).
1987. 'Water chemistry in the Monasavu Reservoir and Wailoa River, Viti Levu, Fiji.' (University of the South Pacific: Suva).
- RESH, V.H., BARNES, J.R. & CRAIG, D.A. 1990. Distribution and ecology of benthic macroinvertebrates in the Opunohu river catchment, Moorea, French Polynesia. *Annales de Limnologie* 26(2-3): 195-214.

## CORAL REEF SPONGES OF THE SAHUL SHELF — A CASE FOR HABITAT PRESERVATION

JOHN N.A. HOOPER

Hooper, J.N.A. 1994 06 30: Coral reef sponges of the sahul shelf — a case for habitat preservation. *Memoirs of the Queensland Museum* 36(1): 93-106. Brisbane. ISSN 0079-8835.

Three adjacent coral reef systems were surveyed (Ashmore-Cartier-Hibernia reefs) on the Sahul Shelf, northwestern edge of the Australian continental plate. 138 species of sponges (Porifera) in 77 genera and 38 families were found. Although sponge species diversity was similar between each of reef system, there was low congruence in species composition despite their close proximity (about 50km apart): Ashmore-Hibernia (13%); Hibernia-Cartier (24%); Cartier-Ashmore (9% similarity). The sponge fauna was divisible into four faunistic groups. 1. Widely distributed Indo-west Pacific species, known from Burma to New Caledonia, including apparently opportunistic species found predominantly on coral substrates. 2. Large populations of autotrophic sponges, characteristic of the shallow water, inner sandy zone and intertidal zones on the reef flat, accounting for most of the coral reef sponge biomass and also found on many Indo-west Pacific coral reefs. Together these two groups comprise only about 16% of species. 3. Coastal and shelf species more-or-less widespread throughout tropical Australasia, comprising about 25% of all species recorded. 4. Species found predominantly in restricted or specialised habitats on the reef comprise the greatest diversity (59%) of sponges in these reef systems, but most of these are poorly documented and known from single or few localities and isolated records in the literature. Differences in species composition between the three reef systems were correlated with both major and minor differences in the geomorphology of particular reef systems. These findings suggest that the concept of a 'ubiquitous coral reef sponge fauna' is too simplistic. Different reefs contain different faunas, largely dependent on the presence or absence of particular habitats. These data, using sponges as an example, have implications for the special management of biodiversity in coral reef systems by habitat conservation in preference to preservation of particular taxa in the tropical marine benthos. Evidence presented here questions the validity of preserving only a single reef as being 'representative' of a system of reefs. □ *Porifera*. Sahul Shelf, Ashmore Reef, Cartier Island, Hibernia Reef, faunal survey, sponge biodiversity, habitat conservation.

John N.A. Hooper, Queensland Museum, PO Box 3300, South Brisbane, Qld. 4101, Australia; 22 July 1993.

As for many other groups of marine invertebrates (Briggs, 1987), northern Australian - southern Indonesian marine habitats may contain the highest diversity of sponge species in Recent seas, and the region is often considered to be the centre of dispersal for Indo-Pacific species (Lévi, 1979). In fact, nearly 2000 nominal species of sponges have been described from this region, but it is still considered to be barely known (Hooper & Lévi, 1994). Large collections of sponges have now been made from the more turbid, nutrient rich shallow coastal waters in both northwest Australia (review in Hooper, 1988) and southeast Indonesia (review in van Soest, 1989, 1990), although many of these species records have not yet been published. Similarly, several large collections of sponges from deeper water reefs on the shelf and slope on the western side of the continent exist, but these too remain largely un-

published (Hooper, unpublished data), whereas sponges living on oceanic coral reefs, on the edge of the western continental margin, have neither been collected nor studied previously. By comparison, sponge faunas from coral reefs on the east coast of Australia are comparatively well known (e.g. Burton 1934; Bergquist, 1969; Bergquist et al., 1988; Wilkinson 1987, 1988; Wilkinson & Cheshire, 1989), as they are in several major reef systems in the western Indian Ocean (e.g. Seychelles, Maldives; see summary in Thomas, 1973).

This is the first published report of a sponge fauna from oceanic coral reefs on the northwestern continental margin of Australia. This paper concentrates on the question of sponge species diversity of three prominent reefs, Ashmore, Cartier, and Hibernia Reefs, comparing differences in species composition between each



reef; examining the various factors that potentially contribute to these differences; and contrasting these differences to the reef geomorphology. These data have implications to the conservation and selection of coral reefs as habitat preserves.

Detailed descriptions of habitats, stations surveyed, and methods of collection are given by Russell & Hanley (1992) and Hooper (1992). Three reef systems were studied. Ashmore Reef was visited in March 1981 (RV 'Hai Kung'), July 1986 (MV 'Coral ReefTel') and August 1987 (MV 'Reef Seeker'); Cartier Island and Hibernia Reef were visited in May 1992 (RV 'Rachel'). Sponges were collected along random transects, using SCUBA, to depths of 30m. Underwater photography, using both 35mm-still and 8mm-video formats, were used to supplement manual collections of samples. Species composition, distribution and abundance of sponges were determined from taxonomic studies of samples (using methods described by Hooper, 1991) and comparative analyses of photographic transects. Only two species were unable to be differentiated from photographic records [*Xestospongia testudinaria* (Lamarck) and *X. bergquistia* Fromont], which are lumped together in this study under the former name. The taxonomic scheme (Table 1) follows Hooper et al. (in press).

## RESULTS AND DISCUSSION

### SAHUL SHELF

Ashmore Reef (12°17'S, 123°02'E), Cartier Island (12°32'S, 123°33'E) and Hibernia Reef (11°58'S, 123°22'E) lie near the outer edge of the Australian continental margin in the Timor Sea, about 350km off the Kimberley coast (840km west of Darwin, 640km NNE of Broome), and 115km from the southern Indonesian island of Roti. These reefs are situated on the Sahul Shelf, at the edge of the Australian plate, at a zone of subduction with the southeastern Indonesian plate (see illustration in Michaux, 1991: fig. 2).

The Sahul Shelf consists of a shallow central basin (called the Bonaparte Depression, <140m depth), rising to ridges 20-50m deep on the outer edges and contiguous with the Kimberley coast on its eastern side. On the northern and northwestern edges of the Sahul Shelf the continental margin drops away rapidly to >2000m depth, where the Australian and Indonesian plates meet (Timor trough). All three reefs lie very close to this drop-off, and they are probably influenced to a greater extent by oceanic upwelling from the

trough, rather than terrestrial runoff as is the case for most reefs closer to the continent.

Ashmore, Cartier and Hibernia Reefs are part of a larger system of exposed coral reefs, submerged coral shoals and drowned reefs running along the northwestern margin of the Australian continent. Although only 9 of these reefs are now fully exposed, classed as 'platform reefs' [Rowley Shoals (Imperieuse, Clerke and Mermaid Reefs; 18-17°S), Browse Island (14°S), Scott Reef (14°S), Seringapatam Reef (13.5°S), Cartier Island, Ashmore Reef and Hibernia Reef], it is thought that this whole area once contained many more active coral reefs during times of lower sea levels, comparable to some areas of the Great Barrier Reef (Edgerley, 1974; Van Andel & Veevers, 1967; well illustrated in Butlin, 1979). Despite the absence of an extensive barrier reef on the Sahul Shelf it is nevertheless still classed as a major reef province (Burrell et al., 1991).

### GEOMORPHOLOGY OF THE REEFS

**Ashmore Reef.** It is a large platform reef (often called a 'shelf atoll'), 27km long, 14km wide, with a large circumferential outer reef, broken only on the northern side, a large shallow, very heavily silted central lagoon, and several sand cays (Fig. 1). Ashmore Reef is situated on a platform projecting from the westernmost ridge of the Sahul Shelf, averaging about 50m depth, with drop-offs to 200m almost immediately to the west and south. The prevailing swell and wind is from the south or southeast, which is reflected in the reef's morphology, being orientated east-west, with the outer reef best defined on the southern and southeastern margins. Maximum spring tidal range is 4.7m, and there is no impounding of water within the lagoon due to several large breaks in the outer reef.

The *Lithothamnion* reef crest is unbroken on the south and southeastern sides, with some coral boulder accumulations on the windward side, whereas it is broken by several passages on the northern (leeward) side, leading into two shallow lagoons (maximum 46m deep), many submerged patch reefs ('bommies'), and three low, vegetated, permanently exposed sand cays. The southern outer reef slope is initially gentle, producing a broad shelf 150m wide with extensive spur and groove formations, before dropping down more steeply in close proximity to the reef. Abutting the inner side of the southern reef crest is a reef flat composed of coral rubble and slabs, coral sediments and live coral pools. The inner

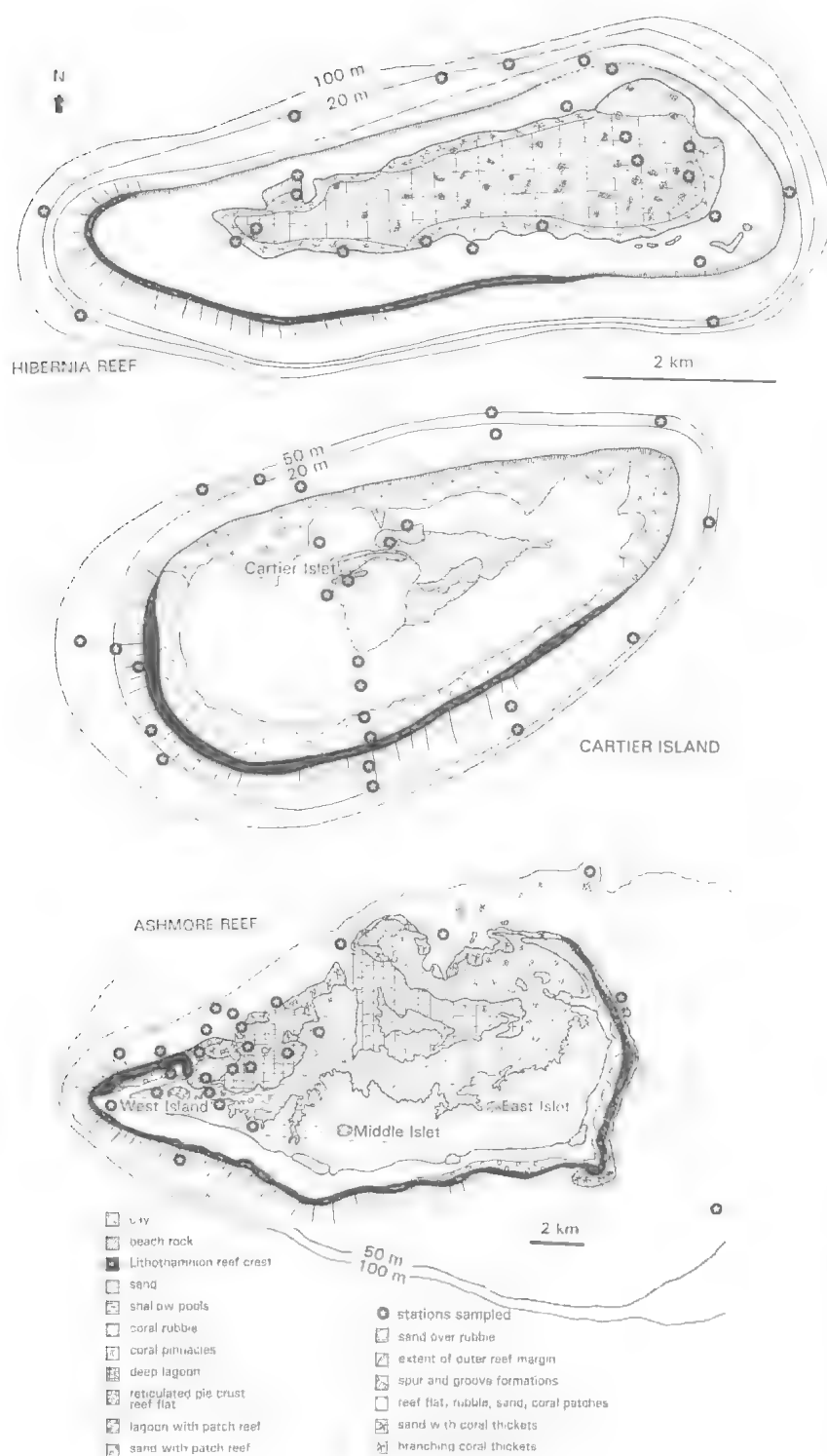


FIG. 1. Geomorphology of Hibernia, Cartier and Ashmore Reefs, Sahul Shelf, indicating major habitat types, compiled from aerial photographs (Australian Survey Office), Russell & Hanley (1992), Berry (1993), and from unpublished collection data (NT Museum, Darwin).

sand flat is very extensive, occupying possibly half the inner reef area, composed of carbonate sediments (mostly foraminiferan and mollusc debris), sparse *Thalassia* beds and algal turf. The macrobenthos here appears to be poor in structure and diversity. The northern outer reef slope is initially sheer but then the slope tapers to 50m depth, becoming continuous with the Sahul Shelf. The northern reef flat is more narrow, with little or no inner sand flat, and generally carries a richer benthos than does the sand flat on the southern margin (compiled from NT Museum unpublished data, and Berry, 1993).

**Cartier Island.** The reef is orientated east-west, lying on a platform about 50-70m deep projecting from the western edge of the Sahul Shelf, and is also exposed to swell and wind predominantly from the southern side. This windward part of the reef lies close to the edge of the continental slope, rising directly from about 180m from the south. However, Cartier Island has a very different geomorphology from both Ashmore and Hibernia Reefs (Fig. 1).

It is an oval-shaped raised platform reef, 4.5km long, 2.3km wide, lacks a lagoon, and possesses a single unvegetated sand cay that becomes submerged during spring tides. The *Lithothamnion* reef crest is only noticeably developed on the island's southwest, which also has an extensive coral boulder zone behind the reef crest. The outer reef slope on the island's south and west is substantially more extensive than that of Ashmore Reef, running about 500m seawards from the reef crest. Here there are extensive spur and groove formations and many large caverns between 10 and 30m depth. On the island's southeast, the outer reef slope is much narrower, dropping vertically to about 200m depth in a very short distance, whereas on the northern side it is almost sheer for about 30m depth but then the plateau levels at about 50-70m, prolific coral substrate merging into coralline sand. The outer reef margins on the island's north and east are diffuse, composed of consolidated pavement leading almost directly into sand and patch reef. An extensive rubble-sand-patch reef flat occupies most of the island's subtidal zone including two small shallow pools. Abundant *Thalassia* and phototrophic sponges were present on the reef flat (compiled from NT Museum unpublished data, Russell & Hanley, 1992, and Berry, 1993).

**Hibernia Reef.** It lies on the northwestern edge of the Sahul Shelf, rising from about 100m depth on all sides but dropping to 300m quite close to the northwestern edge of the reef. Hibernia Reef

is a raised platform reef, 7.7km long, 2.2km wide, with a nearly continuous outer reef around its perimeter, a deep lagoon, and no cay (Fig. 1). The *Lithothamnion* reef crest is well defined only along the southern and western margins, indicating that the prevailing swell and wind may come from this direction.

Although virtually continuous, with well developed coral boulders cemented the reef flat, the reef margin is sunken slightly on its northeastern edge, allowing limited vessel passage into the lagoon, but there is obvious impounding of water within the lagoon during low tide. The lagoon is large, occupying more than half the reef's area, and deep (although not yet completely surveyed it averages about 30m depth, dropping to below 60m in places). Surrounding the inner margin of the reef, relatively homogenous on all sides, is a well developed reef flat. There is an extensive back reef margin of branching coral thickets at both the western and eastern margins, although in the west these thickets drop quickly to very fine coralline sand slopes, and at the northeast inner margin there is an extensive coral scree slope forming the lagoon entrance. Throughout the lagoon are large patch reef pinnacles, rising 30-50m from the lagoon floor, a dominant feature of the lagoon. The outer reef slope on the southern and western sides of Hibernia Reef is extensive, although spur and groove formations were not seen to be as well developed as the other reefs. On the northern side there is a sheer slope to about 50m, whereas on the eastern side rubble seems to dominate the outer reef area (compiled from NT Museum unpublished data, and Russell & Hanley, 1992).

#### DISTRIBUTION PATTERNS OF MARINE INVERTEBRATES

From the known distributions of a few marine invertebrate groups on the outer shelf reef systems of the western continental margin (e.g. Wilson, 1978; Berry, 1986, 1993; Wilson & Allen, 1987; Morgan & Wells, 1991; Pearce & Walker, 1991; Morgan, 1992; Marsh et al., 1993), several biogeographic models have been proposed and a number of pertinent factors have been identified that potentially contribute to these distributions.

It is worthwhile here to briefly summarise these factors, as they relate to sponge populations, since this information is relevant to the interpretation of species distribution patterns.

**Dispersal potential.** Phyla with both demersal and pelagic larval strategies are known to have

differing distributions and dispersal abilities. This explanation has been used to (partially) explain observed differences in distributions of echinoderms on some of these oceanic, outer shelf coral reefs of Western Australia (Marsh et al., 1993). By comparison, phyla with pelagic larval strategies may be much more widely distributed throughout Indo-west Pacific reef systems (e.g. corals). The third dispersal strategy, phyla with only short-lived, demersal larvae (such as sponges with a creeping blastula larva), pose an enigma in terms of resolving their potential for only short-range dispersal versus confirmed observations on relatively wide distributions for a small number of species.

Both vivipary (brooding larvae) and ovipary (broadcasting gametes) are common sexual reproductive strategies in sponges. Over short distances (or short periods of time) sexual reproductive products are undoubtedly effective in recruitment of reef sponges, but for long range dispersal their effectiveness is questionable [short lived demersal larvae, short lived gametes (e.g. about <24 hours)]. However, it is suspected that asexual (clonal) modes of dispersal are widespread, particularly in tropical sponge populations (e.g. Battershill & Bergquist, 1990), where fragments of adult sponges 'tumbleweed' across the substrate (although pelagic rafting in sponges is probably minimal; Boury-Esnault & Lopes, 1985). This does not explain how allegedly widely distributed Indo-west Pacific species are able to cross deep water barriers, and this is a question pertinent to dispersal of 'coral reef sponges' separated by deep troughs (e.g. New Caledonia and Great Barrier Reef).

*Survivorship and growth.* Although commensals on sponges are very common (including shrimps, crabs and holothurians), predators of sponges are known only to include fishes, turtles and a few other invertebrates such as nudibranch molluscs (e.g. Randall & Hartman, 1968; McClintock, 1987). Their fixed, sedentary lifestyle precludes sponges from actively evading predators or defending themselves, but they are thought to be capable of doing so using an array of noxious chemicals (e.g. Bakus, 1981; Bakus et al., 1989), which, Bakus & Ormsby (1994) hypothesise, have evolved for this specific purpose. But these 'biologically active' chemicals are also known to be important as offensive mechanisms in competition for space (e.g. Buss, 1976), and this hypothesis now has some good empirical support [such as their prevalence in crowded, cryptic communities versus exposed,

open ones (e.g. Uriz et al., 1991)]. Whichever hypothesis is correct, sponge survivorship appears to be strongly chemically mediated.

Sponges are predominantly heterotrophic, obtaining their nutrients from filter feeding suspended particles in the water column. As heterotrophs many species are efficient in surviving in high silt, high energy environments, but they are also relatively slow growing as compared with other benthic marine invertebrates such as ascidians and corals. Heterotrophic sponges do not generally compete well with scleractinian corals, for example, in clear waters (the latter have a competitive advantage in using nutrients produced by the photosynthetic activities of their symbiotic zooxanthellae).

Autotrophic (phototrophic) sponges obtain some nutrients from the photosynthetic by-products of symbiotic cyanobacteria. Unlike most heterotrophic species, autotrophs have relatively fast growth rates and are the predominant primary producers in some clear water reef habitats (e.g. reef flats) (Wilkinson, 1987). Autotrophs are more efficient competitors in these habitats, but their distribution is severely restricted to shallow, clear waters. Generally, however, sponges survive well in high energy environments and under relatively adverse conditions (surge, swell, current, sediment loads). These conditions often cause fragmentation and fragments can readily disperse and reattach to the seabed.

*Biogeographic affinities.* Precise biogeographical affinities of the northern Australian sponge fauna are still uncertain, although it is now clear that it is composed of several very different elements (Hooper & Lévi, 1994). Lévi (1979) and Wiedenmayer (1985) speculated that this fauna was predominantly southeastern Indonesian in origin, but more recent empirical evidence indicates that there are relatively higher levels of endemism than expected, ranging from 30-50% (varying between particular families (Hooper, 1991), with small regional enclaves of endemic species along the western and northwestern coasts (e.g. Houtman-Abrolhos Islands, Shark Bay, Darwin Harbour; Hooper & Lévi, 1994). By comparison, other areas appear to have very few indigenous species (e.g. Gulf of Carpentaria), and these differences are probably at least partly due to the differences in age of the Australian coastline, as described and illustrated by Jones & Torgersen (1988). This explanation is plausible to account for the colonisation and affinities of the sedentary marine invertebrates,

such as sponges, on these western oceanic coral reefs, as they were once suspected of being connected by extensive emergent reefs and shallow-water shoals to the Pleistocene continental coastline (e.g. Butlin, 1989).

It is expected that the three reefs investigated in this study would contain a mixture of both Indonesian 'colonising' species and Australian 'endemic' species, lying as they do on the northwestern margin of the Australian plate. This mix of faunas has been demonstrated in several other phyla of marine invertebrate, such as molluscs (e.g. Wells, 1986), crustacea (e.g. Morgan & Wells, 1991) and echinoderms (e.g. Marsh et al., 1993), but not previously for the sponge fauna. Furthermore, because these three coral reef systems are in close proximity to each other, each less than about 50 km apart and interconnected by the shallow Sahul Shelf with its numerous submerged shoals, it is expected that each reef would contain the same, or at least very similar, sponge species.

This null hypothesis is not upheld by present data.

**Habitat availability.** Overlaying these biogeographical relationships are complex patterns related to specific ecological requirements of particular species. Coral reefs are well known for their heterogeneity (Huston, 1985), and typically contain many more potential niches than most temperate ecosystems. Sponges occupy many of these niches in coral reef systems, some opportunistic (growing in many habitats on the reef) and some highly specialised (restricted to one or few). Examples of the latter include: encrusting mats found on shallow water beach rock; seagrass beds; burrowing into mud and other soft sediments; bioeroding coralline substrates; cryptic encrusting (sciaphilic) species; 'living fossil' (reef-building) coralline species found at the base of most coral reefs; and the remarkable shallow-water autotrophic fauna. The ecology and distribution of these autotrophic species, suited to clear water coral reef habitats, has been well documented on the Great Barrier Reef (e.g. Wilkinson 1987, 1988; Wilkinson & Cheshire, 1989; Bergquist et al., 1988), but prior to the present work it was not known whether these were also prevalent on the coral reefs of the western continental margin. By comparison, the species composition of the inshore, more turbid water sponge faunas differs between the west and east coasts of Australia (e.g. Hooper, 1991; Hooper & Lévi, 1994), which may be at least partly explained by the very different geological

histories of the tropical reefs on both sides of the continent, particularly reflected by the absence of a barrier reef on the west coast (Edgerley, 1974; Burrell et al., 1991).

Both opportunistic and ecologically specialised sponge faunas have been recorded from many Indo-west Pacific coral reefs, from which earlier workers concluded that general distributions of 'coral reef sponges' were relatively homogenous across the Indo-west Pacific (e.g. Burton, 1934). This is implicit in much of the older literature, whereas it is shown in this study that the composition of the reef sponge fauna may vary considerably depending on the presence or absence of particular habitats.

#### OBSERVED DISTRIBUTION PATTERNS AND AFFINITIES OF THE SPONGE FAUNA

Prior to these present surveys the sponge fauna of Ashmore, Cartier and Hibernia Reefs was unknown. This study collected 139 species of sponges (although only 138 are differentiated, *X. testudinaria* and *X. bergquistia* combined as they could not be distinguished from video records), belonging to 77 genera and 38 families (Table 1). Each reef system contains the following number of species: Cartier Island 74 species, Hibernia Reef 73 species and Ashmore Reef 51 species. Contrary to expectations, however, the similarity between the faunas on each of these reefs was low (Fig. 2).

These discrepancies in faunal composition might be an artifact of low sample sizes, whereby accurate comparisons between reefs might not be possible due to the relatively low number of stations from which sponges were recorded. 76 stations (from a total of 113 stations sampled) contained sponges: Cartier Island 26 stations, Hibernia Reef 24 stations, and Ashmore Reef 26 stations. Whilst this explanation is plausible for comparison between Ashmore Reef and the Cartier-Hibernia collections (where only 96 samples of 51 species were collected from Ashmore Reef, no underwater video record was made, and collections were made over three separate trips), it certainly is not true for the comparison between Cartier Island and Hibernia Reef (where techniques were standardised and collecting effort was comparable). It is considered that observed differences in the sponge fauna between these reefs has a real (biological) origin.

Based on their known geographical distributions the sponge fauna was divisible into four major groups.

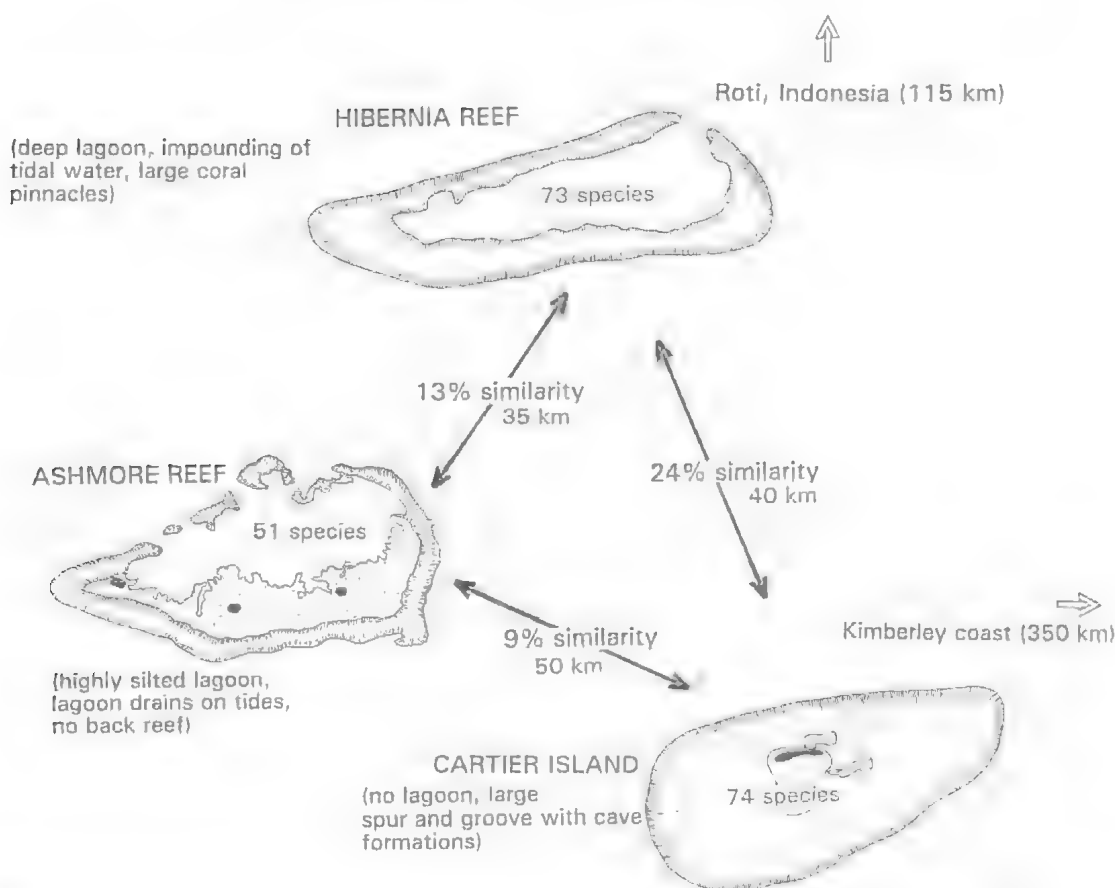


FIG. 2. Similarity in sponge faunas of 3 adjacent coral reefs, Sahul Shelf, indicating number of species on each reef and % similarity in species composition between reef systems.

1. 'Coral reef sponges'. These are widely distributed throughout the Indo-west Pacific, from Burma to New Caledonia (although some species are recorded as widespread, from Madagascar to Polynesia). The distribution of these species appears to be somehow closely linked to the actual distributions of the coral reefs themselves, although it is speculative how their supposedly short lived, poorly motile reproductive products are dispersed across this vast tract of sea (dissected by deep trenches). Most of these species are largely opportunistic, living in many or any zones on the reef. Examples of these are *Aaptos aaptos*, *Axinella carteri*, *Cinachyra australiensis*, *Cribrochalina olemda*, *Echinodictyum mesenterinum*, *Halisarca dujardini*, *Ianthella flabelliformis*, *Jaspis stellifera*, *Phakellia cavernosa*, *P. conulosa*, *Xestospongia testudinaria* and *X. nigricans*. Some 'coral reef sponges' are found associated predominantly with dead coral, on the living reef or in rubble zones, bioeroding the

calcareous substrate (e.g. *Cliona celata*, *Gelliodes fibulatus*, *Iotrochota baculifera*, *I. coccinea*, *Microciona aceratoobtusa*, *Thalysias reinwardti*), or burrowing into both living and dead coral heads (e.g. *Aka mucosa*, *Oceanapia amboinensis*, *Myrmekioderma granulata*, *Spirastrella vagabunda*). All these groups are relatively well documented in both the contemporary and older literature.

2. *Autotrophic sponges*. As expected from literature on other coral reefs (e.g. Wilkinson & Cheshire, 1989), autotrophic species were a prevalent (visually dominant) component of the sponge fauna, with most species recorded from all three reefs. These sponges (with representatives from many families of Porifera), have symbiotic cyanobacteria within their tissues and utilise some or all of the micro-organisms' photosynthetic products for their own nutrition. Thus they are capable of relatively fast growth rates, large individual biomass, large local



population size, and they are apparently responsible for a large proportion of the coral reef's total net primary productivity (e.g. Wilkinson, 1987). Autotrophic sponges are generally restricted to the reef's shallow waters, such as shallow lagoons, inner sandy zones, and intertidal zones on the reef flat, and they include species such as *Carteriospongia foliascens*, *Dysidea herbacea*, *Haliclona cymiformis*, *Pericharax heterorhaphis*, and *Phyllospongia papyracea*.

Our present understanding of 'coral reef sponges' derives mainly from knowledge of both these groups (1 and 2), and yet together they account for only 16% of species diversity within the Ashmore, Cartier and Hibernia Reef systems.

3. *Coastal and shelf species.* 25% of the other species recorded in these surveys are known to be more-or-less widespread in tropical Australasia, found on the more turbid coastal reefs and the shallow continental shelf (e.g. a *Cliona* sp., *Didiscus uceratus*, *Higginsia scabra*, *Raphidotethya enigmatica*, *Reniochalina stalagmitis*, *Teichasnella labyrinthica*).

4. *'Restricted sponge fauna'.* The greatest diversity (59%) of sponges in these reef systems consists of species with restricted or specialised habitats, such as in sheltered waters on the floor of deep lagoons, at the base and on the sides of pinnacles or patch reefs within deep lagoons, in spurs and grooves on the reef front, in caves on the upper reef slope, or associated with seagrass beds in shallow sand flats. Some of these habitats are not present in all reef systems (Fig. 1), and therefore these more restricted species are obviously not present either. This component of the fauna is very poorly known in the literature: species are either undocumented, with several new species from this region already confirmed, or with only a few other isolated records in the literature.

The hypothesis, that the composition of the sponge fauna is largely related to the geomorphology of each reef, is further supported by specific anecdotal examples. *Plakortis mammillaris*, for example, was only found on the outer reef slope, in spur and groove formations and in caves on the fore-reef, which are best represented at Cartier Island, but was not found at either Hibernia or Ashmore Reef. Conversely, *P. nigra* was collected from Hibernia and Ashmore Reefs, on fringing and patch reefs within the lagoon, but was not seen at Cartier Island which has no lagoon. Similarly, *Asteropus surassinerum* is a dominant non-scleractinian species of the benthos in the deeper parts of the lagoons of Hibernia

and Ashmore Reefs, but completely absent from Cartier Island. Differences in the geomorphology of these reefs (e.g. the extent of development of the fore-reef slope, presence and absence of a lagoon system) may be directly responsible for these observed differences in the sponge fauna.

Given the close proximity of the three reefs to each other, each lying at about the same distance from the edge of the continental shelf, and each interconnected by a shallow platform with a number of submerged shoals interdispersed, it is unlikely that any differences in dispersal of reproductive bodies between the reefs could account for the observed differences in sponge species composition. Conversely, it is suggested here that the relatively low levels of similarity between the sponge faunas of Ashmore, Cartier and Hibernia Reefs is related to the presence or absence of particular habitats on each reef (i.e., both major and 'minor' differences in the geomorphology of the reefs). The most obvious differences in reef geomorphology are seen between Cartier Island and the other two reefs (the former with large coral caves and overhangs in the spur and groove formations of the fore-reef zone, and an extensive reef flat; the latter with extensive, relatively deep water lagoons and their associated sheltered-water habitats); less striking, but just as 'effective', are the differences between Ashmore Reef and Hibernia Reef (the former with an unusual highly sedimented lagoon, covering most of its back reef slope - an area which usually has very rich coral growth; and the latter with a nearly continuous outer reef margin, and extensive system of patch reefs within the lagoon). Thus, the concept of a relatively homogenous, ubiquitous 'coral reef sponge fauna', implied in the literature, is an oversimplification: ecological specialisation, as a requirement for survival, is probably more important than previously recognised for sponges (cf. Lévi, 1979; Wiedenmayer, 1985).

That only 25% of all species recorded in this study are known from either (or both) tropical Australian and southern Indonesian waters supports the notion that biogeographic affinities of the sponge fauna on the northwestern continental shelf is not overwhelmingly that of southern Indonesia (Hoooper & Lévi, 1994), as proposed by both Wiedenmayer (1985) and van Soest (1990), but they contain a more complex mix of Australian 'endemics', Indonesian 'invaders', widely distributed oceanic species ('coral reef sponges').

## CONCLUSIONS

Extrapolation of these findings to a conservation strategy for marine resources is appropriate in this forum. One of the main stated functions of a system of marine parks is to provide a reservoir of genetic diversity, to repopulate adjoining areas, as well as to protect particular habitats, marine processes and rare and endangered species (Ivanovici, 1984). Within the various biogeographical provinces there are often small 'representative' habitats set aside as protected areas, on the basis of being 'typical' and containing sufficient resources to fulfil their functions as genetic reservoirs. This is the existing situation for Ashmore Reef, declared a National Nature Reserve in 1983, with the primary stated purpose to protect marine and terrestrial fauna and flora, to protect against possible overfishing, and to act as a representative of an oceanic, outer shelf reef and atoll rising from the edge of the Sahul Shelf. Evidence presented here questions the validity of preserving only a single reef as being 'representative' of, and maintaining genetic resources for, a system of reefs. For one group of marine invertebrates at least, and supported to a some extent by data from other groups [echinoderms (Marsh et al., 1993); molluscs (Wells, 1993)], it is suggested that 'adequate biodiversity' may not be contained within a single reef system. Both subtle and major differences in reef geomorphology appear to substantially influence some faunas. Marine sanctuaries should be designed to contain enough diversity of reef types to provide a true reservoir of genetic diversity.

## ACKNOWLEDGEMENTS

I thank Dr Lyle Vail (now at Lizard Island Research Station), Dr Russell Hanley and Dr Barry Russell (NT Museum), Principal Investigators of various expeditions funded by the Australian National Parks and Wildlife Service (Australian Nature Conservation Agency), for providing me access to these remote faunas; Dr Paddy Berry (WA Museum), through Dr Barry Russell, for access to an unpublished manuscript on Ashmore Reef, and to some of the authors contributing to the Ashmore Reef survey, Mrs Loiset Marsh, Dr Gary Morgan and Dr Fred Wells for permitting me to cite some of their work in press; Dr C.C. Lu (Museum of Victoria) for access to the Taiwanese RV 'Hai Kung' collections; the skipper and crew of the FV 'Rachel' for

great company; and Ms Cathy Johnston, Ms Anne-Marie Mussig, Dr Lyle Vail and Dr Helen Larson for assisting in collecting and photographing sponges from these reefs.

## LITERATURE CITED

- ANDEL, T.H. VAN & VEEVERS, J.J. 1967. Submarine morphology of the Sahul Shelf, northwestern Australia. *Geological Society of America Bulletin* 76: 695-700.
- BAKUS, G.J. 1981. Chemical defense mechanisms on the Great Barrier Reef, Australia. *Science* 211: 497-499.
- BAKUS, G.J., STEBBINS, T.D., LLOYD, K., CHANET, H., WRIGHT, M.T. & BAKUS, G.E. 1989. Unpalatability and dominance on coral reefs in the Fiji and Maldives Islands. *Indian Journal of Invertebrate Zoology and Aquatic Biology* 1: 34-53.
- BAKUS, G.J. & ORMSBY, B. 1994. Comparison of species richness and dominance in northern Papua New Guinea and northern Gulf of Alaska. In Soest, R.W.M. van (ed.), 'Sponges in Time and Space'. (Balkema: Rotterdam).
- BATTERSHILL, C.N. & BERGQUIST, P.R. 1990. The influence of storms on asexual reproduction, recruitment and survivorship of sponges. Pp 397-403. In Ruetzler, K. (ed.), 'New Perspectives in Sponge Biology'. (Smithsonian Institution Press: Washington).
- BERGQUIST, P.R. 1969. Shallow water Demospongiae from Heron Island. *Papers of the University of Queensland Heron Island Research Station* 1(4): 63-72.
- BERGQUIST, P.R., AYLING, A.M. & WILKINSON, C.R. 1988. Poliose Dictyoceratida of the Australian Great Barrier Reef. *Pubblicazione della Stazione Zoologica di Napoli - Marine Ecology* 9(4): 291-320.
- BERRY, P.F. (ed.) 1986. 'Faunal surveys of the Rowley Shoals, Scott Reef and Serangapatam Reef, northwestern Australia'. *Records of the Western Australian Museum, Supplement* 25: 1-106.
- (ed.) 1993. 'Marine faunal surveys of Ashmore Reef and Cartier Island'. *Records of the Western Australian Museum, Supplement* 44: 1-91.
- BOURY-ESNAULT, N. & LOPES, M.T. 1985. Les démosponges littorales de l'Archipel des Açores. *Annales de l'Institut Océanographique, Paris* (612): 149-225.
- BRIGGS, J.C. 1987. 'Biogeography and Plate Tectonics. Developments in Palaeontology and Stratigraphy'. (Elsevier: Amsterdam).
- BURRETT, C., DUMIG, N., BERRY, R. & VARNE, R. 1991. Asian and south-western Pacific Continental terranes derived from Gondwana, and their biogeographic significance. *Australian Systematic Botany* 4: 13-24.
- BURTON, M. 1934. Sponges. In 'Scientific Reports of the Great Barrier Reef Expedition 1928-29'

- Volume 4(14): 513-621. (British Museum (Natural History): London).
- BUSS, L.W. 1976. Better living through chemistry: the relationship between allelochemical interactions and competitive networks. Pp 315-327. In Harrison, F.W. & Cowden, R.R. (eds). 'Aspects of sponge biology'. (Academic Press: New York).
- BUTLIN, N.G. 1989. The palaeoeconomic history of Aboriginal migration. *Australian Economic History Review* 29(2): 3-57.
- EDGERLEY, D.W. 1974. Fossil reefs of the Sahul Shelf, Timor Sea. *Proceedings of the Second International Coral Reef Symposium* 2: 627-637.
- HOOPER, J.N.A. 1988. Structural features of the benthic community of East Point Reef Fish Reserve. A comparative study between oceanic, near-shore and inshore reefs of north-west Australia. In Larson, H.K., Michie, M.G. & Hanley, J.R. (eds). 'Darwin Harbour'. Australian National University North Australian Research Unit Mangrove Monograph (4): 214-225.
1991. Revision of the family Raspailiidae Porifera: Demospongiae, with description of Australian species. *Invertebrate Taxonomy* 5: 1179-1418.
1992. Sponges. In Hanley, J.R. & Russell, B.C. (eds). 'Report on the Marine Resources of Cartier Island and Hibernia Reef, Sahul Shelf'. (Australian National Parks and Wildlife Service: Darwin).
- HOOPER, J.N.A. & LÉVI, C. 1994. Biogeography of Indo-west Pacific sponges: Microcionidae, Raspailiidae and Axinellidae. In Soest, R.W.M. van (ed.), 'Sponges in Time and Space'. (Balkema: Rotterdam).
- HOOPER, J.N.A., WIEDENMAYER, F. & RACEK, A.A. in press. Porifera. In Wells, A. (ed.). 'Zoological Catalogue of Australia. Porifera' (Australian Government Publishing Service, Canberra).
- HUSTON, M. 1985. Patterns of species diversity on coral reefs. *Annual Reviews of Ecology and Systematics* 16: 149-177.
- IVANOVICI, A.M. 1984. Inventory of declared marine and estuarine protected areas in Australian waters. Volumes 1 and 2. Australian National Parks and Wildlife Service, Special Publication (12): 1-433.
- JONES, M.R. & TORGENSEN, T. 1988. Late Quaternary evolution of Lake Carpentaria on the Australia-New Guinea continental shelf. *Australian Journal of Earth Sciences* 35: 313-324.
- LÉVI, C. 1979. The demosponge fauna from the New Caledonia area. In 'Proceedings of the International Symposium on Marine Biogeography and Evolution in the Southern Hemisphere'. New Zealand Oceanographic Institute Special Volume (1979): 307-315.
- MAPSTONE, G.M. 1990. Reef corals and sponges of Indonesia. A video-based learning module. (UNESCO: Paris).
- MARSH, L.M., VAIL, L.L., HOGGETT, A.K. & ROWE, F.W.E. 1993. Part 6. Echinoderms of Ashmore Reef and Cartier Island. In Berry, P.F. (ed.), 'Marine faunal surveys of Ashmore Reef and Cartier Island'. Records of the Western Australian Museum, Supplement 44: 53-65.
- MCCLINTOCK, J.B. 1987. Investigation of the relationships between invertebrate predation and biochemical composition, energy content, spicule armament and toxicity of benthic sponges at McMurdo Sound, Antarctica. *Marine Biology* 94: 479-487.
- MICHAUX, M. 1991. Distributional patterns and tectonic development in Indonesia: Wallace reinterpreted. *Australian Systematic Botany* 4: 25-36.
- MORGAN, G.J. (ed.) 1992. 'Survey of the aquatic fauna of the Kimberley islands and reefs, Western Australia'. Unpublished technical report of the Western Australian Museum Kimberley Island and Reef Expedition, August 1991. Pp 1-113. (Western Australian Museum: Perth).
- MORGAN, G.J. & WELLS, P.E. 1991. Zoogeographic provinces of the Humboldt, Benguela and Leeuwin Current systems. In Pearce, A.F. & Walker, D.I. (eds). 'The Leeuwin Current: and influence on the coastal climate and marine life of Western Australia'. *Journal of the Royal Society of Western Australia* 74: 59-69.
- PEARCE, A.F. & WALKER, D.I. 1991. 'The Leeuwin Current: and influence on the coastal climate and marine life of Western Australia'. *Journal of the Royal Society of Western Australia* 74: 1-140.
- RANDALL, J.E. & HARTMAN, W.D. 1968. Sponge-feeding fishes of the West Indies. *Marine Biology* 1(3): 216-225.
- RAVEN, P.H. 1992. The global significance of Australia's biodiversity. *Australian Biologist* 5(1): 9-13.
- RUSSELL, B.C. & HANLEY, J.R. 1992. 'Survey of the marine biological and heritage resources of Cartier and Hibernia Reefs, Timor Sea'. Pp 1-180, pls 1-26. (Australian National Parks and Wildlife Service: Darwin).
- SOEST, R.W.M. VAN 1989. The Indonesian sponge fauna: a status report. *Netherlands Journal of Sea Research* 23(2): 223-230.
1990. Shallow-water reef sponges of eastern Indonesia. Pp 302-308. In Rützler, K. (ed.), 'New Perspectives in Sponge Biology'. (Smithsonian Institution Press: Washington).
- THOMAS, P.A. 1973. Marine Demospongiae of Mahe Island in the Seychelles Bank (Indian Ocean). *Annales du Musée Royal de l'Afrique Central*

TABLE 1. List of sponge species collected from Cartier, Hibernia and Ashmore Reefs, showing distribution within the three reefs and extra-limital distribution where known. Species numbers refer to as yet unidentified, possibly new species in NTM and QM collections.

- Tervuren, Belgique (Sciences Zoologiques) (203): 1-91.
- URIZ, M.J., NARTIN, D., TURON, X., BALLESTEROS, E., HUGHES, R. & ACEBAL, C. 1991. An approach to the ecological significance of chemically mediated bioactivity in Mediterranean benthic communities. *Marine Ecology Progress Series* 70: 175-188.
- WELLS, F.E. 1986. Zoogeographical affinities of prosobranch gastropods of offshore coral reefs. 1993. Part 4. Molluscs of Ashmore Reef and Cartier Island. In Berry, P.F. (ed.), 'Marine faunal surveys of Ashmore Reef and Cartier Island.' Records of the Western Australian Museum. Supplement 44: 25-45.
- WIEDENMAYER, F. 1985. Perspectives in taxonomy of Australian marine sponges. In Abstracts of the 3rd International Conference on the Biology of Sponges, Woods Hole, USA, November 17-23 1985. (Smithsonian Institution Press: Washington).
- WILKINSON, C.R. 1987. Productivity and abundance of large sponge populations on Flinders Reef flats, Coral Sea. *Coral Reefs* 5(4): 183-188.
1988. Foliose Dictyoceratida of the Australian Great Barrier Reef. 2. Ecology and distribution of these prevalent sponges. *Marine Ecology* 9(4): 321-328.
- WILKINSON, C.R. & CHESHIRE, A.C. 1989. Patterns in the distribution of sponge populations across the central Great Barrier Reef. *Coral Reefs* 8: 127-134.
- WILSON, B.R. (ed.) 1978. 'Biological survey of Mitchell Plateau and Admiralty Gulf, Kimberley, Western Australia'. Western Australian Museum: Perth.
- WILSON, B.R. & ALLEN, G.R. 1987. Major components and distribution of marine fauna. Pp 43-68. In Dyne, G.R. & Walton, D.W. (eds), 'Fauna of Australia. General Articles', Volume 1A. (Australian Government Publishing Service: Canberra).

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
Class Calcarea				
Order Leucettida: Family Leucettidae				
<i>Pericharax heterorhaphis</i> (Polejaeff)	+	+	+	(N coast, GBR, S Indonesia)
Class Demospongiae				
Order Homosclerophorida: Family Plakinidae				
<i>Plakortis mammillaris</i> (Lendenfeld)	+	—	—	(GBR, E Indonesia)
<i>Plakortis nigra</i> Lévi	—	+	—	(E Indonesia, Red Sea)
'Order Lithistida': Family Theonellidae				
<i>Theonella cylindrica</i> Wilson	+	+	—	(S Philippines, Indonesia)
Order Spirophorida: Family Tetillidae				
<i>Cinachyra australiensis</i> (Carter)	+	+	—	(NE & NW coasts, E & W Indonesia, Malay., SW Pac.)
<i>Cinachyra schalzei</i> (Keller)	+	—	—	(E Indonesia)
<i>Cinachyra</i> sp. 333	—	—	+	(unknown)
<i>Cinachyra</i> sp. 409	—	—	+	(unknown)
<i>Craniella</i> sp. 402	—	—	+	(NW shelf)
<i>Raphidothya enigmatica</i> Burton	—	—	+	(NE & NW coasts)
<i>Tethyopsilla</i> sp. 1105	+	—	—	(unknown)
<i>Tetilla</i> sp. 594	—	+	—	(NW coast)

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
Order Astrophorida: Family Coppattiidae				
<i>Asteropus sarassinorum</i> Thiele	—	+	+	(E Indonesia)
<i>Asteropus</i> sp. 1091	+	+	—	(unknown)
<i>Jaspis stellifera</i> (Carter)	+	+	—	(Indo-West Pacific)
<i>Jaspis</i> sp. 1005	—	+	—	(GBR, New Caledonia)
<i>Jaspis</i> sp. 1093	+	—	—	(unknown)
<i>Jaspis</i> sp. 1097	+	+	—	(unknown)
Order Astrophorida: Family Ancorinidae				
<i>Ancorina</i> sp. 797	—	—	+	(unknown)
<i>Stelletta globostellata</i> Carter	+	+	—	(E Indonesia)
Order Hadromerida: Family Chondrillidae				
<i>Chondrosia</i> sp. 1083	+	—	—	(unknown)
Order Hadromerida: Family Clionidae				
<i>Cliona celata</i> Grant	+	+	—	(NW coast)
<i>Cliona</i> sp. 32	—	+	—	(NW & NE coasts)
<i>Cliona</i> sp. 114	—	+	—	(NW coast)
Order Hadromerida: Family Suberitidae				
<i>Aaptos aaptos</i> (Schmidt)	+	+	—	(widespread Indo-West Pacific)
<i>Suberites</i> sp. 634	—	—	+	(unknown)

TABLE 1. (continued)

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
Order Hadromerida: Family Spirastrellidae				
<i>Spirastrella vagabunda</i> (Ridley)	+	—	—	(NW coast, E Indonesia, S Philippines, W Pacific)
<i>Spirastrella</i> sp.89	—	+	—	(NW coast)
<i>Spirastrella</i> sp. 480	—	—	+	(unknown)
Order Hadromerida: Family Tethyidae				
<i>Tethya</i> sp.939	+	—	—	(Gulf of Thailand)
Order Hadromerida: Family Latrunculiidae				
<i>Latrunculia</i> sp.1048	—	+	—	(PNG)
Order Halichondrida: Order Desmoxiidae				
<i>Higginsia</i> sp.1059	+	—	—	(unknown)
<i>Higginsia scabra</i> Whitelegge	+	—	+	(NW coast, GBR)
<i>Myrmekioderma granulata</i> (Esper)	+	+	—	(Indo-West Pacific)
<i>Myrmekioderma</i> sp.1092	+	—	—	(unknown)
Order Halichondrida: Family Axinellidae				
<i>Acanthella</i> sp.836	+	+	—	(S Australia)
<i>Axinella</i> sp.26	—	—	+	(S Australia)
<i>Axinella carteri</i> (Dendy)	+	+	+	(Indo-Pacific)
<i>Axinella</i> sp.1089	+	—	—	(unknown)
<i>Pseudaxinella</i> sp.662	+	—	—	(GBR)
<i>Phakellia cavernosa</i> (Dendy)	+	—	+	(NW coast, GBR, Thailand, New Caledonia, E Indonesia)
<i>Phakellia conulosa</i> Dendy	+	+	—	(Indo-Pacific)
<i>Phakellia dendyi</i> Bergquist	+	+	—	(NZ, PNG, NW coast, S Philippines)
<i>Phakellia</i> sp.646	+	—	—	(GBR, PNG, NW coast)
<i>Reniochalina stalagmitis</i> Lendenfeld	+	+	+	(N & NW coasts)
<i>Reniochalina</i> sp.172	+	—	—	(NW coast)
<i>Reniochalina</i> sp. 798	—	—	+	(unknown)
<i>Teichaxinella labyrinthica</i> (Dendy)	+	—	—	(NW shelf)
<i>Teichaxinella</i> sp. 1012	—	—	+	(unknown)
Order Halichondrida: Family Halichondriidae				
<i>Didiscus aceratus</i> (Ridley & Dendy)	+	—	—	(NW coast)

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
<i>Epipolasis</i> sp. 799	—	—	+	(unknown)
<i>Halichondria</i> sp. 775	—	—	+	(unknown)
<i>Halichondria</i> sp.778	+	—	+	(NW shelf)
<i>Halichondria</i> sp.786	+	—	—	(Timor Sea)
<i>Halichondria</i> sp. 802	—	—	+	(unknown)
Order Agelasida: Family Agelasidae				
<i>Agelas mauritiana</i> Carter	+	—	—	(Indo-Pacific)
Order Agelasida: Family Astroscleridae				
<i>Astrosclera willeyana</i> Lister	+	+	—	(GBR, Christmas I., E Indonesia)
Order Poecilosclerida: Family Desmacellidae				
<i>Biemna</i> sp. 793	—	—	+	(NW shelf)
Order Poecilosclerida: Family Desmacididae				
<i>Batzella</i> sp.1096	+	+	—	(unknown)
<i>Desmacidon</i> sp.980	—	+	—	(GBR, NW coast)
<i>Desmapsamma</i> sp.800	+	+	+	(NW shelf)
<i>Iotrochota baculifera</i> Ridley	+	+	+	(Indo-West Pacific)
<i>Iotrochota coccinea</i> (Carter)	+	+	—	(Indo-West Pacific)
Order Poecilosclerida: Family Hymedesmidae				
<i>Hymedesmia</i> sp.1098	+	+	—	(unknown)
Order Poecilosclerida: Family Microcionidae				
<i>Microcionia acerateobtus</i> Carter	+	+	—	(Indo-Pacific)
<i>Thalysias coppingeri</i> (Ridley)	—	—	+	(NW & NE coasts)
<i>Thalysias reinwardti</i> (Vosmaer)	+	+	—	(W Pacific—E Indonesia)
<i>Thalysias tingens</i> Hooper	—	+	—	(NW coast)
<i>Thalysias toxifera</i> (Hentschel)	+	+	—	(NW coast, E Indonesia)
<i>Antho (Dirrhopatum) ridleyi</i> (Hentschel)	—	+	—	(Arafura & Timor Seas)
Order Poecilosclerida: Family Raspailiidae				
<i>Ectyoplasia tabula</i> (Lamarck)	—	+	—	(N & NW coasts & shelf)
<i>Echinodictyum cancellatum</i> (Lamarck)	—	+	—	(NW & NE coasts, E Indonesia)
<i>Echinodictyum mesenterinum</i> (Lamarck)	—	+	+	(circum-Australia, prob. Indo-West Pacific)

TABLE 1. (continued)

SPECIES	REEF SYSTEM			Extra-limital distrib.
	CARTIER	HIBERNIA	ASHMORE	
Order Poecilosclerida: Family Crellidae				
<i>Crella spinulata</i> (Hentschel)	—	+		(GBR, NW coast & shelf, Houtman-Abrolhos Is, New Caledonia)
Order Poecilosclerida: Family Mycalidae				
<i>Arenochalina</i> sp. 795	—	—	+	(unknown)
<i>Mycale</i> ( <i>Carmia</i> ) sp. 239	—	—	+	(NW coast)
Order Haplosclerida: Family Petrosiidae				
<i>Petrosia ushmorica</i> (Hooper)	—	—	+	(endemic)
<i>Petrosia</i> sp. 113	+	—	—	(NW coast, Thailand)
<i>Petrosia</i> sp. 1021	—	+	—	(S Philippines)
<i>Petrosia</i> sp. 1095	+	—	—	(unknown)
<i>Petrosia</i> sp. 1103	+	—	—	(unknown)
<i>Strongylophora strongylata</i> (Thiele)	+	—	—	(NW shelf, E Indonesia)
<i>Xestospongia exigua</i> (Kirkpatrick)	+	+	—	(GBR, PNG, NW coast, Christmas I)
<i>Xestospongia nigricans</i> (Lindgren)	+	+	+	(E Indonesia)
<i>Xestospongia testudinaria</i> (Lamarck)	+	+	+	(Indo-West Pacific)
Order Haplosclerida: Family Chalinidae				
<i>Acervochalina confusa</i> Dendy	+	—	—	(Indian Ocean)
<i>Adocia</i> sp. 171	—	+	—	(NW coast)
<i>Adocia</i> sp. 384	—	—	+	(unknown)
<i>Haliclona</i> sp. 945	+	—	—	(Burma, SW Thailand)
<i>Haliclona</i> sp. 1022	+	+	—	(S Philippines)
<i>Reniera</i> sp. 789	—	+	+	(PNG)
<i>Reniera</i> sp. 801	—	—	+	(unknown)
<i>Reniera</i> sp. 1046	—	+	—	(PNG)
<i>Haliclona cymiformis</i> (Esper)	+	+	+	(NE & NW coasts, PNG, S Indonesia, W Pacific)
Order Haplosclerida: Family Callyspongiidae				
<i>Callyspongia schulzei</i> Kieschnick	—	+	—	(NW coast, E Indonesia)
<i>Callyspongia</i> sp. 407	—	—	+	(unknown)
<i>Callyspongia</i> sp. 755	+	—	—	(Shark Bay)

SPECIES	REEF SYSTEM			Extra-limital distrib.
	CARTIER	HIBERNIA	ASHMORE	
<i>Callyspongia</i> sp. 791	—	—	+	(unknown)
<i>Callyspongia</i> sp. 803	—	—	+	(unknown)
<i>Callyspongia</i> sp. 938	+	—	—	(Thailand)
<i>Callyspongia</i> sp. 1107	—	+	—	(unknown)
Order Haplosclerida: Family Niphatidae				
<i>Amphimedon</i> sp. 881	+	—	—	(Thailand)
<i>Cribrochalina olemda</i> de Laubenfels		+	—	(NW coast, E Indonesia, Palau, Truk, S Philippines)
<i>Cribrochalina</i> sp. 792	+	—	+	(PNG)
<i>Cribrochalina</i> sp. 1108		+	—	(unknown)
<i>Gelliodes fibulatus</i> (Carter)	+	+	—	(widespread Indo-Pacific)
<i>Gelliodes</i> sp. 555	—	—	+	(unknown)
<i>Gelliodes</i> sp. 619	+	—	—	(NW coast & shelf)
<i>Gelliodes</i> sp. 1049	—	+	—	(PNG)
<i>Aka mucosa</i> (Bergquist)	+	—	—	(Indo-West Pacific)
<i>Aka</i> sp. 1102	+	—	—	(unknown)
Order Haplosclerida: Family Oceanapiidae				
<i>Oceanapia ambainensis</i> Topsent	+	+	+	(NW coast, S Indonesia)
<i>Oceanapia</i>	—	+	—	(NW coast & shelf)
<i>Pellina</i> sp. 805	—	—	+	(unknown)
<i>Pellina</i> sp. 1101	+	—	—	(unknown)
Order Dictyoceratida: Family Spongiidae				
<i>Carteriospongia flabellifera</i> (Bowerbank)	—	+	+	(GBR, PNG, E Indonesia)
<i>Carteriospongia foliascens</i> (Pallas)		+	+	(widespread Indo-Pacific)
<i>Dactylospongia elegans</i> (Thiele)	+	+	—	(GBR, E Indonesia)
<i>Hyrrias</i> sp. 796	—	—	+	(unknown)
<i>Phyllospongia pupyracea</i> (Esper)	+	+	+	(widespread Indo-Pacific)
<i>Spongia</i> sp. 15	—	—	+	(NW coast)
Order Dictyoceratida: Family Irciniidae				
<i>Aplysinopsis reticulata</i> (Lendenfeld)	+	+	—	(N & NW coasts)
<i>Aplysinopsis elegans</i> Lendenfeld	—	—	+	(N Australia)
<i>Fascaplysinopsis reticulata</i> (Hentschel)	+	+	—	(E Indonesia, SE Qld, GBR)



TABLE 1. (continued)

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
<i>Ircinia</i> sp. 1	—	—	+	(N Australia)
<i>Luffariella</i> sp. 804	—	—	+	(unknown)
<i>Thorecta</i> sp. 11	—	—	+	(NW coast)
Order Dictyoceratida: Family Dysideidae				
<i>Dysidea arenaria</i> Bergquist	+	—	—	(GBR, Thailand, Palau Is)
<i>Dysidea granulosa</i> Bergquist	—	+	—	(Palau Is)
<i>Dysidea herbacea</i> (Keller)	+	+	+	(Indo-Pacific)
Order Verongida: Family Druinellidae				
<i>Pseudoceratina</i> sp. 190	—	—	+	(unknown)
<i>Pseudoceratina</i> sp. 364	+	+	+	(NW coast)

SPECIES	REEF SYSTEM			
	CARTIER	HIBERNIA	ASHMORE	Extra-limital distrib.
Order Verongida: Family Aplysinidae				
<i>Aplysina ianthelliformis</i> Bergquist & Tizard	+	+	—	(NW coast)
<i>Aplysina</i> sp. 125	—	—	+	(unknown)
Order Verongida: Family Ianthellidae				
<i>Ianthella flabelliformis</i> (Pallas)	—	+	—	(Indo-West Pacific)
<i>Ianthella</i> sp. 993	+	—	—	(GBR)
Order Dendroceratida: Family Darwinellidae				
<i>Aplysilla</i> sp. 688	—	+	—	(Indo-Pacific)
Order Dendroceratida: Family Halisarcidae				
<i>Halisarca dujardini</i> Johnston	—	+	—	(? widespread Indo-Pacific)

## ORIBATIDS - A MITE BIODIVERSE (ACARINA)

GLENN S. HUNT

Hunt, G.S. 1994 06 30: Oribatids - a mite biodiverse (Acarina). *Memoirs of the Queensland Museum* 36(1): 107-114. Brisbane. ISSN 0079-8835.

Oribatids are reviewed for scientists/managers assessing whether to incorporate this group into their biodiversity or biomonitoring studies in Australia. Oribatids usually feed on soil fungi, bacteria, decaying plant material or a combination of these. They inhabit the soil in virtually all terrestrial ecosystems. Their biodiversity largely results from heterogeneities that this environment can provide. There are about 50 families, 120 genera and 220 species described from Australia representing respectively about 25%, 10% and 3% of the World's oribatid fauna. The utility of available keys is discussed and 11 family level taxa are reviewed in terms of their potential contribution to biodiversity research. Scanning electron micrographs are used to illustrate some important morphological characters. □ *Acarina, Oribatida, biodiversity, biomonitoring, external morphology, Australian fauna.*

*Glenn S. Hunt, Division of Invertebrate Zoology, Australian Museum, P.O. Box A285, Sydney South, NSW, 2000, Australia, 3 August 1993.*

Oribatid mites (Suborder Oribatida or Cryptosigmata) are a dominant component of ground litter and soils in virtually every habitat, with some reports of densities exceeding 100,000 per m<sup>2</sup> (Norton, 1985). Many species are associated with moss and fungi, and a varied arboreal fauna is now being recognised in Australia (Walter & Behan-Pelletier, 1993; Walter et al., 1994).

This paper is intended as a brief review of the group for scientists or managers assessing whether to incorporate oribatids into their biodiversity or biomonitoring studies. The biodiversity of oribatids is examined from different perspectives. The most useful keys and a selection of taxa which seem to have potential value in Australian biodiversity research are briefly discussed. Reference is made to the more instructive papers on biology and ecology, most of which, unfortunately, deal with the Northern Hemisphere fauna.

### ORIBATID BIODIVERSITY - PERSPECTIVES

Ancestral oribatids probably evolved in the Lower Devonian as saprophages in the early, developing soils (Norton et al., 1988). Apart from relatively minor but multiple forays into arboreal and aquatic habitats (and the radiation of the Astigmata), their descendants have remained in or close to the soil, evolving to take advantage of niche opportunities that heterogeneities in this habitat provide. Today, as many as 80 or more species may occupy the same area of forest floor contributing significantly to the biodiversity of the ecosystem.

Oribatid biodiversity can be viewed from different perspectives depending on the aims of the research. Thus, if the contribution of oribatids to decomposition processes in soil is the focus of research, biodiversity from the functional perspective of feeding biology will be of prime interest.

Oribatids are usually microphytophages (feeding mainly on soil fungi), macrophytophages (feeding on decaying leaf or woody material) or panphytophages, feeding on both fungi and decaying plant material (Luxton, 1972, 1991; Norton, 1985, 1990). Some can swap food preferences depending on availability, or show opportunistic polyphagy by including nematodes in their diet. The most detailed analyses of oribatid biodiversity in terms of feeding biology are those of Schuster (1956) and Luxton (1972).

Oribatids are mostly particulate feeders producing faecal pellets. They thus contribute to soil structure and facilitate litter decomposition by increasing the surface area available for attack by micro-organisms.

Partly because of their eclectic feeding tastes, oribatid populations seem to be relatively stable compared with the more 'r-selected' Collembola and fungivorous Prostigmata whose reproduction appears to be more responsive to changes in fungus supply (Norton, 1985). This generalisation may not hold in all environments or species. For example, Kinnear (1993) demonstrated marked fluctuations in numbers of certain species in coastal habitats north of Perth. These may be due to seasonal fluctuations in moisture though more research is required to demonstrate this.

Oribatid biodiversity can also be viewed across ecosystem types, between habitats or from one microhabitat to another. Large differences in diversity can be expected between, say, arid and moist montane ecosystems where vicariance as well as ecosystem effects contribute to biodiversity. A significantly reduced difference in species turnover might be expected between adjacent rainforest and sclerophyll communities where differences in temperature, humidity, litter type and soil may be among the important parameters. Lee (1985b) has presented preliminary data on oribatid faunal differences across different habitat types, both natural and modified, in South Australia. In natural habitats, he found both increased abundance and species richness with increased rainfall; low species richness in cultivated sites though a few species were very abundant. His final report is in preparation (Lee, pers. comm.), its utility greatly increased by Lee's taxonomic studies (see references).

Small-scale habitat changes on the forest floor, from litter to lichen and moss to mushroom, have been related to changes in oribatid species composition (Aoki, 1967; Hammer, 1972; Wunderle, 1992) and hence contribute to oribatid biodiversity. More subtle changes in microhabitat preferences, for example within the litter layer, may result in patchy lateral distributions of individual species. Parameters including variation in moisture, litter depth and altitude have been implicated in spacial changes in biodiversity on a seemingly uniform forest floor (Mitchell, 1978; Walter, 1985). In an elegantly designed study, Anderson (1978) demonstrated significant correlations between mite diversity and vertical microhabitat diversity in the soil and litter profile. Walter & Norton (1984) studied sympatric congeners in pine litter soil. They hypothesised that the non-random separation in body size ranges, in one case involving four *Scheloribates* spp., enabled the congeners to use the resources of soil spaces of different sizes, perhaps reducing competition.

## ORIBATIDS AND BIOMONITORING

Oribatids have been used in other countries for monitoring the effects of pollution, reclamation of mining sites, reforestation, silvicultural practices, hazard reduction burning and other perturbations (see Marshall et al., 1987 for references). In Australia, Kinnear (1991) demonstrated a marked reduction in numbers of individuals in sites more affected by mining activities. For ex-

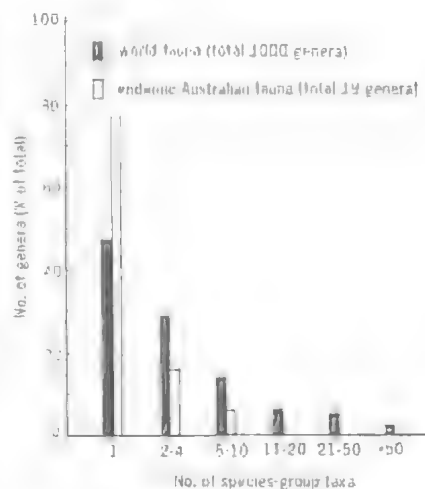


FIG. 1. Relative frequency of species-group taxa in World and 'endemic' Australian genera (World data adapted from Norton (1985))

ample, sampled numbers of *Aphelacarus* sp. individuals varied from 34 to 264 on the three less disturbed sites and from 1 to 10 on the three more disturbed sites. Effects of burning have been studied in Australia by Moulton (1982) and Noble et al. (1989) with both studies attempting to identify to species level where practicable. Moulton defined two groups of oribatids in terms of their response to fire. Not unexpectedly, the group inhabiting surface layers was more seriously affected than the more euedaphic group. However, it would be interesting to know what 'trickle-down' effect frequent long term burning, an all-too-common practice in Australian forest management, has on deeper fauna.

Cranston (1990) lists seven criteria to assess suitability of taxa for biomonitoring. Oribatids perform strongly on most criteria: they are exposed to a variety of environmental parameters which affect the soil, they are functionally important in soil formation, they are ubiquitous, the numbers of species in a given locality are (probably) within manageable limits and have been shown to be responsive to certain environmental perturbations. However, their small size, difficulty in identifying many taxa to species level (and immaturity of our taxonomic knowledge), abundance of individuals often encountered, some difficulties in standardising sampling and extraction, and time taken in sorting are all negative aspects.

Difficulties with identification and numbers of individuals may be circumvented by the careful selection of 'priority taxa' which are more readily

recognisable but still representative of an important feeding guild or species assemblage. For example, *Otocepheidae* (below) warrant investigation as a potential representative group, at least for moister habitats.

## IDENTIFICATION KEYS

A good place to start is with Norton's (1990) simplified and illustrated 'beginner's' key to family level taxa. Although intended for the North American fauna, the characters of value can quickly be appreciated and courage fortified before plunging deeper into the group. Norton's key can be supplemented by that of Moldenke & Fichter (1988) which contains useful SEM images and a glossary, as well as a general key to immatures. Luxton's (1985) comprehensive key to genus level for the New Zealand fauna is also useful as Australia has many taxa in common. Keys to several Australian taxa are given by Lee (see his papers referenced below for further citations). I am currently examining the feasibility of an Australian key for the non-specialist to family and where practicable to genus level, illustrated by SEMs as well as line-drawings.

In a recent key to World genera (Balogh & Balogh, 1992), Volume I contains keys and family lists, and Volume II ventral and dorsal illustrations of an exemplar from most genera. Apart from the illustrations which can frequently be used to arrive at a 'ball-park' family or genus, it suffers from some major disadvantages. It is not particularly 'user-friendly' and resort has to be made to Balogh & Mahunka (1983) for an explanation of terminology and zoogeographical abbreviations (latter not wholly consistent). There is no bibliography, though this gap can be filled in large part by Fujikawa (1991). Species numbers given for genera apparently include unpublished records.

The key also reflects a highly split, artificial classification with a plethora of monobasic taxa. As Norton (1985) points out, this type of classification may assist identification but can hinder, rather than advance, ecological and biogeographical generalisations based on an understanding of phylogeny. Unfortunately, their key ignores or overlooks some advances which have been made in our knowledge of higher level relationships. However, until there is a rival synthesis, Balogh and Balogh's key will continue to dominate oribatid classification.

	World fauna	Australian fauna	% of world fauna
No. of families	200	50	25
No. of genera	1000	100	10

TABLE 1. Relative numbers of described oribatid taxa in World and Australian faunas

## OVERVIEW OF AUSTRALIA'S ORIBATID FAUNA

R.B. Halliday's 'Checklist and Bibliography' of Australian Acarina (Halliday, in prep) will be a valuable access point to the literature. He records approximately 50 families, 120 genera and 220 species from Australia, which represent respectively about 25%, 10% and 3% of the World's oribatid fauna (Table 1). In comparison, the North American fauna (Marshall et al., 1987) comprises about 120 families, 320 genera and 1200 species (respectively 60%, 27% and 16% of the World fauna). Of the Australian fauna, 1 family and 20 genera may at present be regarded as 'endemic', though 16 (80%) of these genera are monotypic (Fig. 1). These figures indicate the Australian fauna is poorly known particularly at the species level. Many other genera are represented in Australia (pers. obs.; D. C. Lee, pers. comm.) but have yet to be recorded in the published literature.

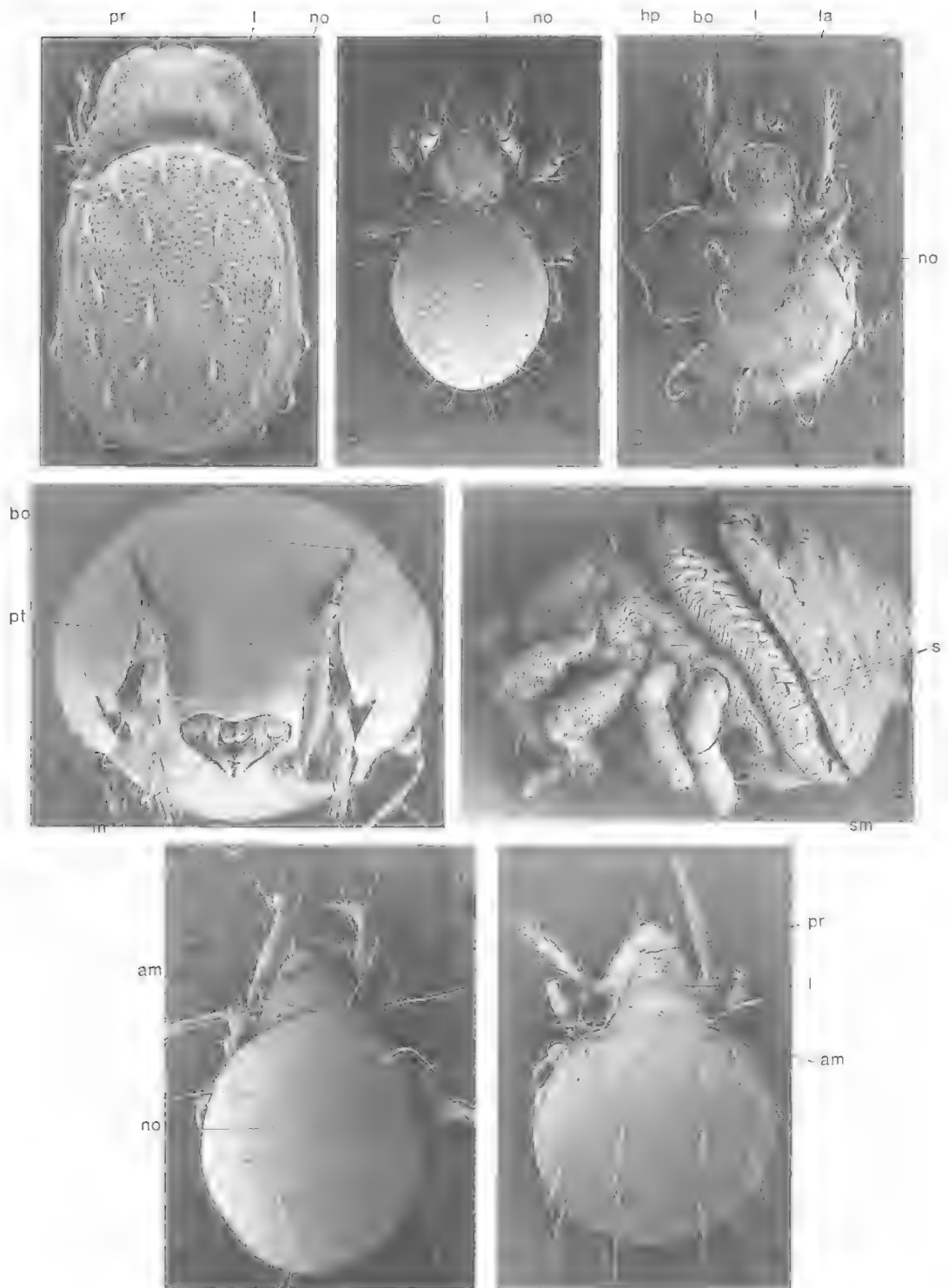
Some family level taxa appear to have more potential in biodiversity studies because they are more abundant, readily recognisable and/or better known at the species level. Other families are less 'user-friendly'. The following is a discussion of 11 family level taxa (citing of references not exhaustive).

Structures referred to in square brackets indicate some important characters labelled in the figures but are not necessarily diagnostic of each family.

(a) *Otocepheidae* (Fig. 2B). These are relatively large bodied, recognisable and among the more common mites in moister areas of Australia, especially *Pseudotocepheus* J. Balogh. A few species have been described by Balogh & Balogh (1983a, b).

(b) *Carabodidae* (Fig. 2A). Similar comments to the above apply, though these mites are not as plentiful in most samples. Some idea of range in variation is given by Balogh & Mahunka (1978)

(c) *Eutegaeidae* (Fig. 2C). These are similarly large and easily recognisable oribatids but tend to be less numerous in samples than the families



above. The superfamily Eutegaeoidea is reviewed by Luxton (1988) and keys given for families, genera and species.

(c) *Oppiidae* (Fig. 2F). These are among the most numerous and speciose oribatids in Australia but are also among the smallest and most difficult to identify. For example, a slide ostensibly of one oppiid morphospecies, proved to contain two families and three genera when examined by a specialist (D.C. Lee, pers. comm.). Perhaps a good, though narrow, introduction to the group and the type of systematic problems encountered is Lee & Subias (1991), who also list pertinent references to Australian species. Several Australian species originally placed in *Oppia* have been transferred to other genera as a search through Subias & Balogh (1989) reveals. Species are frequently lumped as 'Oppiidae' in ecological studies because of difficulty with identification.

(d) *Scheloribatidae* (not illustrated). This major group presents similar problems to the Oppiidae in terms of identification. An excellent grounding to the major genus in Australia, *Scheloribates* Berlese, is provided by Lee & Pajak (1990) (though Lee has developed a different setal nomenclature to that in common use). These authors report difficulty in separating infra- from interspecific variation but have found leg characters useful in delineating species. *Scheloribates* is widely distributed across a variety of Australian ecosystems and is an important intermediate host for tapeworms (Lee & Pajak, 1990).

(e) *Oribatulidae* (Fig. 2G). Like its closely related family above (d), some species occur in pasture, and may act as intermediate hosts for tapeworms (Roberts, 1953). About 15 species have been described from Australia with a sound foundation for the group established by Lee (1992). The 25 'oribatulid' species recorded by Lee (1985b) across different habitats in South Australia include some scheloribatid species (Lee, pers. comm.).

(f) *Phthiracaridae* (Fig. 3A). (including *Steganacaridae* of Niedbala, 1992). This is a group of 'box-mites' which is abundant in berlesates and which is featured on the 'Clunies Ross' side of Australia's \$50 note. Unfortunately, it and related families seem to be a grave-yard for many-a-misidentified taxon at the genus and species levels (see Niedbala, 1992). The single most important paper on the Australian fauna is Niedbala (1987). *Notophthiracarus* Ramsay is the most nominally speciose oribatid genus in Australia with 19 species described to date. The superfamily Phthiracaraoidea has been monographed on a world basis by Niedbala (1992) who discusses important characters and gives a generic level cladistic analysis. A major review of the Tasmanian fauna is in preparation (W. Niedbala & M. Colloff, pers. comm.).

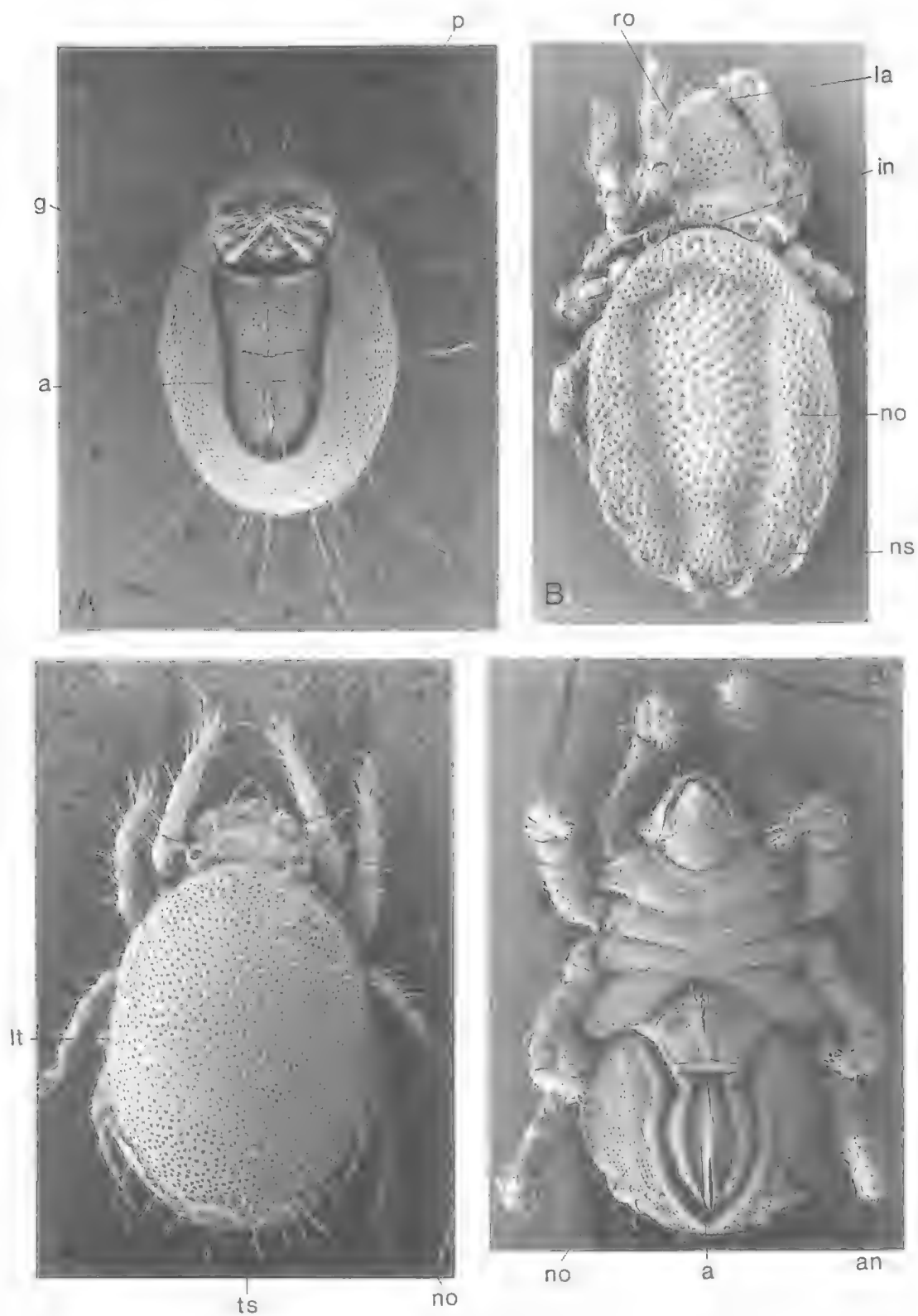
(g) *Galumidae* (Fig. 2D). This is generally regarded as one of the most highly derived oribatid families in which various extensions of the exoskeleton enclose virtually all vulnerable parts. Although large bodied, a detailed study of setae and areae porosae is usually required to make species determinations. Balogh & Balogh (1983a) describe some species, while J. Stary of the Czech Republic (pers. comm.) is working on other elements of our fauna.

(h) *Pedrocortesellidae* (Fig. 3B). Although only four nominal species, all in *Pedrocortesella* Hamner, have been described (P. Balogh, 1985), this family and the closely allied *Pheroliodidae* have undergone major radiations in Australia, particularly in drier habitats. I am currently revising these groups.

(i) *Hermanniellidae* (Fig. 3C). Although not recorded in the Australian literature, this distinctive group is well represented in numbers of individuals, if not species, in many litter samples and appears to occur across a variety of ecosystems. *Hermanniella* Berlese is common in eastern Australian samples.

(j) *Brachychthoniidae* (not shown). This is one of the so-called 'primitive' or 'inferior' oribatid

FIG. 2. Variation in some oribatids. A = Carabodidae: no = notogaster oval, often heavily ornamented and with leaf-like setae; prodorsum broad, almost as wide as notogaster; l = lamella rounded, not blade-like. B = Otocephalidae: no = notogaster oval; c = condyles on prodorsum oppose condyles on notogaster; l = lamella narrow, almost a costula. C = Eutegaeidae: no = notogaster rounded, lip = humeral process or projection; bo = bothridium forming laterad expansion of prodorsum; l = lamella very large and blade-like; la = lamellar seta on cuspis. D = Galumidae: pt = body with lateral wing-like flaps (pteromorphs) which are movable about a hinge and beneath which legs can retract, pteromorph extends anterior to bothridium; bo = bothridium; m = mouth-parts largely covered by extensions of cuticle (teeta). E = Lioididae: s = scapulae (notogastral exuviae) of preadult instars; sm = body large and dark coloured, with striated margins. F = Oppiidae: no = notogaster globular and smooth; am = anterior margin of notogaster convex. G = Oribatulidae: am = anterior margin of notogaster not clearly delineated, notogaster fused with prodorsum; l = lamella narrow. Not to scale.





families. Some species are significant in drier habitats (Lee, 1985b; A. Kinnear, pers. comm.) but they are very small bodied. Some of the other primitive groups are covered by Lee (1985a) and his earlier work.

Many families not included in the above discussion may prove to be of considerable importance when the Australian fauna is better known. Some families and genera can be locally important. For example, *Liodes* sp. (Liodidae) (Fig. 2E), hitherto unrecorded in Australia, is quite common in the Brisbane area, while *Novonothrus* sp. (Nothridae) (Fig. 3D) is a dominant species in nearby Lamington National Park.

### ACKNOWLEDGEMENTS

An Australian Biological Resources Study grant is supporting my research on oribatids. Bruce Halliday, CSIRO, Canberra has been most helpful in making his draft 'Checklist and Bibliography' on Australian Acarina available for my use. Roy Norton, State University of New York, Dave Walter, University of Queensland, and Bruce Halliday commented on the manuscript. Suzanne Lindsay did the SEMs and Roger Springthorpe the camera ready layouts.

### LITERATURE CITED

- ANDERSON, J.M. 1978. Inter- and intra-habitat relationships between woodland Cryptostigmata species diversity and the diversity of soil and litter microhabitats. *Oecologia* (Berlin) 32: 341-348.
- AOKI, J. 1967. Microhabitats of oribatid mites on a forest floor. *Bulletin of the National Science Museum, Tokyo* 10(2): 133-138.
- BALOGH, J. & BALOGH, 1983a. New oribatid mites from Australia (Acari: Oribatei). *Acta zoologica Academiae Scientiarum Hungaricae* 29(1-3): 81-105.
- 1983b. Data to the oribatid fauna of Australia (Acari). II. *Acta zoologica Academiae Scientiarum Hungaricae* 29(4): 283-301.
1992. The oribatid mites genera of the world, Vols I & II. (Hungarian Natural History Museum: Budapest).
- BALOGH, J. & MAHUNKA, S. 1978. Data to the oribatid fauna of Australia (Acari). I. *Opuscula zoologica*, Budapest 15(1-2): 31-49.
1983. Primitive oribatids of the Palaearctic Region. (Series Eds: Balogh, J. & Mahunka, S. *The Soil Mites of the World*, I.) (Elsevier: Amsterdam).
- BALOGH, P. 1985. New oribatids from Australia (Oribatei). *Opuscula zoologica*, Budapest 19-20: 49-56.
- CRANSTON, P.S. 1990. Biomonitoring and invertebrate taxonomy. *Environmental Monitoring and Assessment* 14: 265-273.
- FUJIKAWA, T. 1991. List of oribatid families and genera of the World. *Edaphologia* 46: 1-130.
- HAMMER, M. 1972. Microhabitats of oribatid mites on a Danish woodland floor. *Pedobiologia* 12: 412-423.
- KINNEAR, A. 1991. Acarine communities of semi-arid soils from the Eastern Goldfields region of Western Australia. *Pedobiologia* 35: 273-283.
1993. Biodiversity of litter organisms: the impact of litter type. Abstracts, 'Towards Biodiversity and Conservation.' A Conference on Invertebrate Conservation and Biodiversity. Queensland Museum, Brisbane, 12-15 July 1993.
- LEE, D.C. 1985a. Sarcopiformes (Acari) of South Australian soils. 4. Primitive oribatid mites (Cryptostigmata) with an extensive, unfissured hysteronotal shield and aptychoid. *Records of the South Australian Museum* 19(4): 39-67.
- 1985b. Mites of South Australian soils. Pp. 57-59. In Greenslade, P. & Majer, J.D. (eds), *Soil and Litter Invertebrates of Australian Mediterranean-type ecosystems*. WATTE School of Biology Bulletin 12, Adelaide.
1992. New species of Oribatulidae (Acari: Cryptostigmata: Planofissurae) from South Australian soils, with a review of subfamilies and Australian records. *Records of the South Australian Museum* 26: 37-49.
- LEE, D.C. & PAJAK, G.A. 1990. *Scheloriabates* Berlese and *Megascheloriabates* gen. nov. from southeastern Australia, with comments on Scheloriabidae (Acari: Cryptostigmata: Oribatoidea). *Invertebrate Taxonomy* 4: 205-246.
- LEE, D.C. & SUBIAS, L.S. 1991. *Bruchioppiella* species (Acari: Oribatida: Oppiidae) from South Australian soils. *Records of the South Australian Museum* 25(1): 19-30.

FIG. 3. Variation in some oribatids. A = Phthiracaridae: p = body form ptychoid, i.e. prodorsum can fold ventrad onto notogaster completely enclosing legs and gnathosoma, g and a = genital plates and anal plates broad, together forming large part of venter. B = Pedrocorresellidae: no = notogaster flatish or concave, la = lamellar seta mesad and anterior to rostral seta; ro = rostral seta; in = interlamellar seta minute; ns = notogastral setae restricted to posterior margin. C = Hermannellidae: n = notogaster oval and convex, often punctate, shown here with tritonymphal sculp largely removed; lt = lateral tube carrying pore of hystric gland; ls = remnant of tritonymphal sculp with its setae. D = Nothridae: no = notogaster wraps around to ventral side but does not fuse in ventral mid-line; a = anal plates; an = adanal plates not fused to anal plates. Not to scale.

- LUXTON, M. 1972. Studies on the oribatid mites of a Danish beech wood soil. *Pedobiologia* 12: 434-463.
1985. Cryptostigmata (Arachnida: Acari) - a concise review. Fauna of New Zealand. (Science Information Publishing Centre, DSIR: NZ), 106pp.
1988. A new mite superfamily (Acari: Cryptostigmata). *Zoological Journal of the Linnean Society* 93: 71-91.
1991. Seasonal and spatial variation in food intake by the oribatid mites of beech woodland soil. pp. 459-471. In Schuster, R. & Murphey, P.W. (eds), *The Acari, reproduction, development and life-history strategies*. (Chapman & Hall: London).
- MARSHALL, V.G., REEVES, R.M., & NORTON, R.A. 1987. Catalogue of the Oribatida (Acari) of continental United States and Canada. *Memoirs of the Entomological Society of Canada* 139: 1-418.
- MITCHELL, M.J. 1978. Vertical and horizontal distribution of oribatid mites in an aspen woodland soil. *Ecology* 59: 302-312.
- MOLDENKE, A.R. & FICHTER, B.L. 1988. Invertebrates of the H.J. Andrews Experimental Forest, Western Cascade Mountains, Oregon: IV. The oribatid mites (Acari: Cryptostigmata). United States Department of Agriculture Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-217: 112pp.
- MOULTON, T.P. 1982. The effect of prescribed burning and simulated burning on soil and litter arthropods in open forest at Cordeaux, N.S.W., Australia. (PhD Thesis, School of Biological Sciences, Macquarie University, Sydney).
- NIEDBALA, W. 1987. Phthiracaroida (Acari, Oribatida) nouveaux d'Australie. *Redia* 70: 301-375.
1992. Phthiracaroida (Acari, Oribatida) Systematic Studies. (Elsevier: Amsterdam).
- NOBLE, J.C., KALISZWESKI, M. & WHITFORD, W.G. 1989. Soil Acari from burnt and unburnt mallee habitats in western New South Wales pp. 224-225. In Noble, J.C., Joss, P.J. & Jones, G.K. (eds), *The mallee lands. A conservation perspective*. CSIRO: 224-225.
- NORTON, R.A. 1985. Aspects of the biology and systematics of soil arachnids, particularly saprophagous and mycophagous mites. *Quaestiones Entomologicae* 21: 523-524.
1990. Acarina: Oribatida. pp. 779-803. In D.L. Dindal (ed.) *Soil Biology Guide*. (John Wiley & Sons: Brisbane).
- NORTON, R.A., BONAMO, P.M., GRIERSON, J.D. & SHEAR, W.A. 1988. Oribatid mite fossils from a terrestrial Devonian deposit near Gilboa, New York State. *Journal of Paleontology* 62: 259-269.
- ROBERTS, F.H.S. 1953. *Zygoribatula longiporosa* Hammer (Oribatei: Acarina), an intermediate host of *Moniezia benedeni* (Moniez) (Anoplocephalidae: Cestoda) in Australia. *Australian Journal of Zoology* 1: 239-241.
- SCHUSTER, R., 1956. Der Anteil der Oribatiden an den Zersetzungsvorgängen im Boden. *Zeitschrift für Morphologie und Ökologie der Tiere* 45: 1-35.
- SUBIAS, L.S. & BALOGH, P. 1989. Identification keys to the genera of Oppiidae Grandjean, 1951 (Acari: Oribatei). *Acta zoologica Hungarica* 35(3-4): 355-412.
- WALTER, D.E. 1985. The effects of litter type and elevation on colonization of mixed coniferous litter bags by oribatid mites. *Pedobiologia* 28: 383-387.
- WALTER, D.E. & BEHAN-PELLETIER, V. 1993. Systematics and ecology of *Adhaesozetes polyphyllos* sp. nov. (Acari: Oribatida: Lichneremaeoidea) leaf-inhabiting mites from Australian rainforests. *Canadian Journal of Zoology* 71: 1024-1040.
- WALTER, D.E., O'DOWD, D.J. & BARNES, V. 1994. The forgotten arthropods: foliar mites in the forest canopy. *Memoirs of the Queensland Museum* 36: 221-226.
- WALTER, D.E. & NORTON, R.A. 1984. Body size distribution in sympatric oribatid mites (Acari: Sarcoptiformes) from California pine litter. *Pedobiologia* 27: 99-106.
- WUNDERLE, I. 1992. Die Oribatiden-Gemeinschaften (Acari) der verschiedenen Habitats eines Buchenwaldes. *Carolinae* 50: 79-144.

## CONSERVATION OF A 'THREATENED BUTTERFLY COMMUNITY' AT MOUNT PIPER, VICTORIA

ANN JELINEK, DAVID R. BRITTON AND TIM R. NEW

Jelinek, A., Britton, D.R. & New, T.R. 1994 06 30. Conservation of a threatened butterfly community at Mount Piper, Victoria. *Memoirs of the Queensland Museum* 36(1): 115-120. Brisbane. ISSN 0079-8835

Mount Piper is an area of outstanding environmental significance. It is currently the focus of study of a 'threatened Butterfly Community'. Mount Piper has the only known occurrence of 'Butterfly Community No.1' listed under Victoria's Flora and Fauna Guarantee Act, 1988. The butterfly assemblage includes two rare Lycaenidae, *Acrodipsas brisbanensis* and *A. myrmecophila*. A combination of legislation, public involvement, regional planning and sponsorship, supported by State and Commonwealth funding for management and research respectively, have greatly assisted with the understanding and long term conservation of this unique environment. □Community, Lycaenidae, *Acrodipsas*, Ant-blue, butterfly, ant, hill-topping, Flora and Fauna Guarantee, Critical Habitat

Ann Jelinek, c/- Australian Nature Conservation Agency, Endangered Species Unit, GPO Box 636, Canberra, ACT, 2601, Australia; David R. Britton and Tim R. New, Zoology Department, La Trobe University, Victoria, 3083, Australia; 28 July 1993.

Mount Piper is a steep, solitary mountain rising from 230m to 440m above an undulating plain between the Tallarook and Mount William ranges in central Victoria (37°12'S, 145°0'E). The cone-shaped mountain is a distinctive local landmark and natural backdrop for Broadford township where it features on the Shire's logo. The Department of Conservation and Natural Resources manages the Mount Piper Education Reserve of 56 ha, which incorporates most of the mountain.

Mount Piper is a quartz plug or epithermal deposit of quartz and other minerals deposited by hot solutions. The quartz capping at the summit is localised. It is virtually an 'island' of natural bushland surrounded by predominantly cleared agricultural land. Remnant bushland on private land links native vegetation on the mountain with roadside and streamside vegetation, providing important wildlife habitats.

The vegetation on Mount Piper is a mosaic of open forest and woodland dominated by Stringybark, Peppermint, Box and Ironbark eucalypts (Ashton, 1976; Cameron et al., 1992). Scattered clumps of Red Stringybark, *Eucalyptus macro-rhyncha* F.Muell. ex Benth. subsp. *macro-rhyncha* and small groups of live, partly dead and dead Lightwood, *Acacia implexa* Benth., occur on the summit. Small, naturally grassy patches with lichen-covered boulders and rock outcrops also occur. Total summit area is about 2000m<sup>2</sup>.

Most of Mount Piper is naturally vegetated although there is evidence of past habitat disturbances. These include tree clearing or trimming of sight lines for the trigonometric station and

around communication towers on the summit, the construction of a steep access road to a radio shed built just below the summit, selective timber cutting, wood collecting, bushwalking, horse riding, trail bike riding, vehicular access, and the invasion of introduced plants (e.g. *Centaureium* sp.), grasses and thistles, livestock, feral goats and rabbits.

Briefly during the late 1940s, Mount Piper was a source of timber for firing boilers at the local Broadford paper mill. Originally, the mill used black coal but later the mill used timber and then brown coal. Earlier, two underground mine tunnels and a mine shaft were constructed and operated in search of antimony and gold. Antimony was mined from 1939 to 1945 but proved unprofitable (Marshall, 1992, pers. comm.).

Mount Piper is an valuable scientific and educational resource. It is currently a focus for butterfly conservation in Victoria.

### SCIENTIFIC SIGNIFICANCE

Mount Piper is recognised for its butterfly diversity and its rare and threatened butterfly species. The attraction of the isolated mountain landscape for hill-topping butterflies and moths makes Mount Piper an important site for monitoring the abundance of significant, hill-topping species. Hill-topping is an effective means of mate location and is an integral part of the life cycles of many butterflies and moths (New, 1991).

Other special features include its interesting

geological formation and distinctive vegetation patterns reflecting changes in aspect and altitude. Mount Piper also provides refuge for various local and migratory native wildlife including koalas (*Phascolarctos cinereus*), rare Regent Honeyeaters (*Xanthomyza phrygia*) and possibly, Brush-tailed Phascogales (*Phascogale taproata*).

In 1989, the introduction of new biodiversity legislation in Victoria, the Flora and Fauna Guarantee Act 1988, and an application for mineral exploration precipitated community interest in Mount Piper. The mountain had previously been popular for recreation and butterfly collecting.

The Flora and Fauna Guarantee Act 1988 aimed to 'guarantee that all taxa of flora and fauna and ecological communities in Victoria can survive, flourish and retain their potential for evolutionary development in the wild'. A community, defined as 'Butterfly Community No. 1', is listed as a threatened community on Schedule 2 of the Act. The butterfly assemblage is characterised by the Small Ant-blue, *Acrodipsas myrmecophila* (Waterhouse and Lyell), Large Ant-blue *Acrodipsas brisbanensis* (Miskin) and Genoveva Azure, *Ogyris genoveva genoveva* (Hewitson). Both *Acrodipsas* species are listed as threatened taxa on Schedule 2 of the Flora and Fauna Guarantee Act 1988. The listed 'Butterfly Community' and taxa are considered to be 'significantly prone to future threats that are likely to result in their extinction, primarily because of their restricted occurrence and sensitivity to environmental conditions'.

The threat of mineral exploration and prospecting on Mount Piper was averted after intense pressure from entomologists, the local community, the Department of Conservation & Natural Resources (then Conservation, Forests & Lands) and Broadford Shire Council. Newspaper headlines declared 'The Minister, Mount Piper and those butterflies!', 'Shire skittles Mount Piper mining', 'Serenity may be a new battleground' and 'Fears that gold search could kill butterflies', thus encouraging a volatile debate. The strong community concern was rekindled recently with another unsuccessful application for mineral exploration, although mineral exploration and mining interests remain.

## 'BUTTERFLY COMMUNITY'

Mount Piper is the core area of a forest habitat that supports 'Butterfly Community No. 1' which includes at least 38 butterfly species, several large, diurnal moth species and many species of ants (Britton & New, 1993):

- 28 butterfly and 7 large, diurnal moth species have been recorded on the summit of Mount Piper, of those 20 of the butterflies have been recorded only on the summit;

- 18 butterfly and 3 large, diurnal moth species are resident; 8 other butterfly and 4 diurnal moth species are also possibly resident within the habitat;

- 13 butterfly species are associated with various species of ants;

- 5 butterfly species use acacias, 5 use mistletoes and 8 use native grasses and sedges for larval food and breeding sites.

Mount Piper is also the only currently known site of *Acrodipsas myrmecophila* in Victoria. It has unusual associations of butterfly species. In particular, it represents a unique co-occurrence of *A. myrmecophila* and *A. brisbanensis*. It supports the rare, diurnal Sun Moth, *Synemon plana* Walker, associated with native grassland habitats. It also has a high diversity of terrestrial and arboreal ants. About 130 morphospecies have been recorded (S. Hinkley, 1993, pers. comm.).

The Mount Piper habitat is important for at least 23 hill-topping butterfly species and one grassland moth (Britton & New, 1993; Common & Waterhouse, 1981; Crosby, 1988; Quick, 1989) (Table 1).

The isolated, distinctive peak of Mount Piper attracts hill-topping butterflies and moths. Males congregate on the summit where they establish and defend territories. Some also attract females and mate. *Acrodipsas* species establish territories on the upper-most branches of the tallest eucalypt; other species use eucalypts, acacias and rocks or settle on the ground. The trigonometric station is rarely used for hill-topping even though it is one of the highest objects on the summit (Britton & New, 1992, 1993).

Interactions between butterflies, particularly hill-topping species seeking limited territorial sites on the summit, and interdependent relationships between some lycaenid species and ants are common. Insectivorous vertebrates, including Grey Fantails (*Rhipidura fuliginosa*), Short-beaked Echidnas (*Tachyglossus aculeatus*),

TABLE 1 Summary of butterflies and diurnal moths recorded on the summit of Mount Piper. Source: Britton & New 1992, 1993, \*C. Beardsell, pers. comm. 1993. X = summit only; X + = summit & elsewhere.

BUTTERFLY SPECIES	CONSERVATION (LOCAL & STATE) & BREEDING STATUS	Recorded
<i>Trapezites phigalioides</i> Waterhouse	common, resident	X
<i>Trapezites phigalia phigalia</i> (Hewitson)*	common, resident	X
<i>Trapezites luteus luteus</i> (Tepper)	localised, resident	
<i>Dispar compacta</i> (Butler)	common, resident	X +
<i>Signeta flammeata</i> (Butler)	sparse, resident	X
<i>Taractroceras papyria papyria</i> (Boisduval)	common, resident	
<i>Ocybadistes walkeri sothis</i> Waterhouse	sparse, possible resident	
<i>Papilio anactus</i> W.S. Macleay	common, vagrant	X
<i>Papilio demoleus sthenelus</i> W.S. Macleay	rare, vagrant	X
<i>Delias aganippe</i> (Donovan)	common, resident	X +
<i>Delias harpalyce</i> (Donovan)	common, resident	X +
<i>Anaphaels java teutonia</i> (Fabricius)	common, vagrant	
<i>Pieris rapae rapae</i> (Linnaeus)	common, vagrant	X +
<i>Appias paulina ega</i> (Boisduval)	rare, migratory vagrant	X
<i>Eurema smilax</i> (Donovan)	rare, migratory vagrant	
<i>Geitoneura klugii klugii</i> (Guérin-Méneville)	common, resident	X +
<i>Heteronympha merope merope</i> (Fabricius)	common, resident	X +
<i>Vanessa kershawi</i> (McCoy)	common, possible resident	X +
<i>Vanessa itea</i> (Fabricius)	common, vagrant	X
<i>Acraea andromacha andromacha</i> (Fabricius)	rare, migratory vagrant	X
<i>Junonia villida calybe</i> (Godart)	common, resident	
<i>Danaus chrysippus penlia</i> (Stoll)	sparse, vagrant	X
<i>Acrodipsas brisbanensis cyrilus</i> (Anderson & Spry)	rare, possible resident. IFFG listed, Rare (Vic)	X
<i>Acrodipsas myrmecophila</i> (Waterhouse & Lyell)	rare, possible resident. IFFG listed	X
<i>Hypochrysops delicia delos</i> (Waterhouse & Lyell)	common, possible resident	X
<i>Ogyris olane ocela</i> Waterhouse	common, resident	X
<i>Ogyris genoveva genoveva</i> (Hewitson)	rare, possible resident	X
<i>Ogyris abrota</i> Westwood	localised, resident	
<i>Neolucia agricola agricola</i> (Westwood)	sparse, possible resident	X
<i>Theclinessthes miskini miskini</i> (T.P. Lucas)	sparse, possible resident	X
<i>Theclinessthes serpentata serpentata</i> (Herrich-Schäffer)	common, vagrant	X
<i>Lampides boeticus</i> (Linnaeus)	sparse, vagrant	X
<i>Zizania labradus labradus</i> (Godart)	common, resident	X
<i>Nacaduba biocellata biocellata</i> (Semper)	common, resident	X
<i>Candalides hyacinthinus simplex</i> (Tepper)	rare, vagrant	X
<i>Lucia limbaria</i> Swainson	occasionally common, otherwise sparse, resident	
<i>Jalmenus evagoras evagoras</i> (Donovan)	localised, resident	
<i>Jalmenus icilius</i> Hewitson	rare, resident	
DIURNAL MOTHS		
<i>Comocrus behri</i> (Angus)	common, resident	X +
<i>Phalaenoides glycine</i> Lewis	common, vagrant	X +
<i>Eutrichopidia latinus</i> (Donovan)	common, possible resident	X +
<i>Synemon plana</i> Walker	occasionally common, otherwise sparse, resident	
<i>Nyctemera amica</i> (White)	common, resident	X
<i>Asura lydia</i> (Donovan)	common, possible resident	X
<i>Utheisa pulchelloides</i> Hampson	common, possible resident	X
<i>Pollanisus viridipulverulentus</i> (Guérin-Méneville)	common, possible resident	X

Grass Skinks (*Lampropholis guichenoti*), and other fauna may also interact with butterflies, moths or ants.

Butterfly and moth larval food plants or ant nests are likely oviposition sites for butterflies and moths. These include acacias and mistletoes, and ant nests in or on tree stumps, beneath bark or in dead or living, standing and fallen eucalypts and acacias. Native grasslands dominated by *Danthonia* spp. provide important habitats for *Synemon plana*, the larvae of which feed on roots of native grasses. Areas with these characteristics occur mainly on the lower slopes of Mount Piper and on surrounding private land and road reserves (Britton & New, 1993).

Symbiotic relationships between butterflies and ants are common. *Acrodipsas myrmecophila* is believed to associate with the Coconut Ant (*Papyrius 'nitidus'*), *Ogyris genoveva genoveva* with the Sugar Ant (*Camponotus 'consobrinus'*), *Jalmenus icilius* with *Iridomyrmex 'vicina'*, *Lucia limbaria* with *Iridomyrmex* sp. (possibly *I. 'itinerans'*), *Hypochrysops delicia delos* with ants of the genus *Crematogaster* and *Jalmenus evagoras evagoras* with species of the small, aggressive, black ants, *Iridomyrmex* spp. (Britton & New, 1993).

Ants attend the caterpillars of these lycaenids. They guide them to food supplies and protect them from disease, parasites and predators (Britton & New, 1992). The female *A. myrmecophila* oviposits on a stump or tree that contains the nest of *P. 'nitidus'*. The ants take the newly hatched larvae into their nest where the larvae feed on material brought into the nest by the ants or by extracting fluids from ant larvae and pupae. Caterpillars pupate inside the nest from which the adult butterflies later emerge (Common & Waterhouse, 1981; Quick, 1989). The life history of *A. brisbanensis* is unknown. Despite intensive searching for *Papyrius 'nitidus'* on and around Mount Piper, including historical occurrences, roadside reserves and private property, no colonies have been located during the past three years of survey.

Caterpillars of *Jalmenus icilius* and *J. evagoras evagoras* feed on *Acacia pycnantha* and *A. mearnsii* respectively; those of *Ogyris genoveva genoveva* and *O. abrota* feed on Box Mistletoe *Ameyma miquelii* and Creeping Mistletoe *Muehlenia eucalyptoides* respectively. Larvae of the hill-topping moth, *Comocrus behri* also feed on *A. miquelii*. Both species of acacias and mistletoes occur in the Mount Piper area.

## THREATS

The most serious, current threats to the butterfly assemblage at Mount Piper are: high intensity and frequent fire; firewood collecting; intensive grazing, soil compaction and increased soil fertility due to livestock; invasive plants and pest animals have potential to significantly change, deplete or compete for food sources, shelter, butterfly and moth oviposition sites and ant nest sites.

Salinity, chemical sprays, tree dieback, rural subdivisions and vegetation clearance, including active removal of native grasses, sedges, mistletoe, acacia seedlings and old standing or fallen acacias and eucalypts can all directly degrade breeding, feeding and shelter sites for butterflies, moths, ants and associated fauna. They can also indirectly affect the habitat by progressively fragmenting remnant bushland around hill-topping and oviposition sites.

Mineral exploration and mining can cause habitat disturbance and pollution on Mount Piper and in adjoining freehold properties and road reserves.

Intensive visitor use of Mount Piper can cause erosion, inhibit regeneration and cause other habitat disturbance unless carefully managed.

Continued use of the summit as a trigonometric station is a threat but only where vegetation is cleared or hinders rehabilitation works and natural regeneration on and around the summit.

## CONSERVATION STRATEGY

The conservation strategy for the Mount Piper environment integrates research, planning and management with community involvement. The strategy recognises community awareness and appreciation about the environmental significance of the butterfly community and its habitat as an integral part of threatened species management and land use planning.

Action Statement No.6 prepared for 'Butterfly Community No. 1' in accordance with the Flora and Fauna Guarantee Act 1988 and a Recovery Plan, Research Phase are currently being implemented (Jelinek, 1991, 1992). These plans concentrate on research and monitoring of the butterflies, day-flying moths and ants at Mount Piper, as well as more detailed studies on selected target species and comparative surveys at other mountain peaks (Britton & New 1992, 1993). Within three years, high priority research and management activities identified in the plans have been completed.



Essential management activities carried out include erosion control and revegetation, restriction of access into the reserve to walkers, removal of disused structures, on-site interpretation, community consultation, removal of livestock and feral goats and hand removal of thistles. The interpretation display and brochure aim to increase community awareness and appreciation of the significance of the Mount Piper environment.

Broadford Shire Council is committed to protecting roadside vegetation in the area from clearing, fire and wood collecting activities. The Geodetic Survey Section of the Department of Survey and Mapping has agreed to minimum site clearance requirements around the trigonometric station required for satellite survey instead of maintaining sight lines for ground survey.

Long term protection of the Mount Piper habitat is also provided by other planning and legislative processes. A 'critical habitat' determination for 'Butterfly Community No.1' is being prepared in accordance with the Flora and Fauna Guarantee Act, 1988. It is based on the known and potential critical habitat requirements of the rare and threatened butterflies and moth recorded for 'Butterfly Community No.1'. Critical habitat is defined as 'the whole or any part or parts of the habitat of the community that is critical to the survival of that community'. Mount Piper forms the core area of the identified 'critical habitat', with the summit being important for hill-topping species and known and potentially important butterfly and moth breeding sites occurring on the lower slopes of Mount Piper, outside Mount Piper Education Reserve.

The Mount Piper habitat, including public and private land, is also on the interim list of the Register of the National Estate based on its significance for invertebrates, particularly butterflies. In addition, a proposed amendment to the Broadford Shire Planning Scheme, known as Amendment L8 (Mount Piper Conservation Zone), reflects the environmental, cultural and scenic significance of the Mount Piper landscape, together with contiguous native or semi-native habitats on private land and road reserves. The policy component of Amendment L8 provides specific controls preventing the removal of native vegetation in all successional stages without a permit. Although statewide native vegetation controls exist, they are inadequate for invertebrate conservation. They do not cover vegetation less than 10 years old, dead standing and fallen trees or in most cases, areas of native vegetation less than 10 hectares.

Prior to the formal exhibition of the proposed Amendment L8 in May 1993, public consultation occurred to clarify the need for the Amendment, its implications for landowners, provide information about the Flora and Fauna Guarantee Act 1988 and discuss the results of management and research work at Mount Piper. The status of Amendment L8 is subject to the recommendations of a Panel Hearing held recently in accordance with the Planning & Environment Act 1987.

Management guidelines, based on the research results, have been developed for managing native and semi-native vegetation on and surrounding Mount Piper for wildlife conservation. These guidelines are included in the L8 Amendment, are actively promoted and are, wherever possible, complemented by joint on-site inspections with landholders. Incentive schemes such as Save the Bush are available to assist landholders with protecting native vegetation remnants.

The guidelines encourage land owners and managers to:

- protect native vegetation remnants;
- maintain community dynamics, especially areas of successional vegetation including acacias and native grasslands, by selective slashing, light grazing or low intensity, infrequent fire;
- promote acacia diversity and native grasslands;
- leave senescent and dead, standing or fallen acacia and eucalypt stems, dead and decaying stumps and leaf litter in native vegetation remnants;
- encourage natural revegetation by fencing out livestock and minimising vehicle use, particularly along water courses and on steep slopes;
- establish strategic plantings of local, native trees and shrubs to connect existing vegetation remnants and provide shelter belts for livestock;
- cease removal of mistletoe and fence areas severely affected by tree dieback and mistletoe to minimise increased fertility and soil compaction due to livestock;
- control invasive plants, particularly blackberries, thistles and pest animals such as goats that degrade native habitats and compete with native fauna;
- participate in the Land for Wildlife Scheme and local Landcare activities.

## SUMMARY

The Mount Piper conservation strategy highlights the significance of mountain landscapes for



invertebrate conservation. It also demonstrates the importance of integrated land management based on an understanding of an area's ecology, rather than concentrating on individual species or being restricted by land tenure.

Consecutive seasons of invertebrate surveys, monitoring and research at Mount Piper have provided significant information on the invertebrate community, important species and habitat characteristics. This work is considerably enhanced by comparative butterfly surveys at other potentially important mountain sites. Key environmental features identified include naturally vegetated mountain landscapes, all successional stages of eucalypts and acacias, decaying ground timber, stumps and leaf litter, mistletoes, native grasses and sedges.

Increased community awareness, improved hilltop management, maintenance of vegetation in a range of successional stages and a study of ant species distributions and ecology within the habitat form the basis for future management and conservation of the threatened butterfly species and community at Mount Piper. Understanding relationships between *Acrodipsas* butterflies and ants will also assist recognition of habitat requirements of these rare and threatened species. Continuing active support of local people, interest groups and scientists is also needed to ensure the long term conservation of this unique ecological community.

#### ACKNOWLEDGMENTS

The authors are grateful for financial assistance provided by the Australian Heritage Commission under the National Estate Grants Program and the Australian Nature Conservation Agency under the Endangered Species Program. These grants have supported the research component of the project. Appreciation is extended to the Australian Geographic Society and the State Government of Victoria for supporting other im-

portant components of this project. Thanks also to D. Crosby and W.N.B. Quick for information about butterflies at Mount Piper and the biology of *Acrodipsas myrmecophila*.

#### LITERATURE CITED

- ASHTON, D.H. 1976. The vegetation of Mount Piper, Central Victoria; a study of a continuum. *Journal of Ecology* 64: 463-483.
- BRITTON, D.R. & NEW, T.R. 1992. Ecology of the butterfly and ant community at Mount Piper, Victoria. (Unpublished report, Department of Conservation and Natural Resources, Victoria).
1993. Communities of diurnal Lepidoptera in central Victoria, with emphasis on the Mount Piper region, Broadford. (Unpublished report, Department of Conservation and Natural Resources, Victoria).
- CAMERON, D., YOUNG, F. & WHITE, M. 1992. Vascular Flora of Mount Piper Education Reserve, Broadford. (Unpublished report, Department of Conservation and Natural Resources, Victoria).
- COMMON, I.F.B. & WATERHOUSE, D.F. 1981. Butterflies of Australia. (Angus & Robertson: Sydney).
- CROSBY, D.F. 1988. The entomological significance of Mount Piper, Broadford. (Unpublished report, Department of Conservation, Forests and Lands, Victoria).
- JELINEK, A. 1991. Butterfly Community No. 1. (Flora and Fauna Guarantee Action Statement No. 6, Department of Conservation and Environment, Victoria).
1992. A Recovery Plan, Research Phase for a threatened butterfly community at Mount Piper in Central Victoria. (Unpublished report, Australian National Parks and Wildlife Service, Canberra).
- NEW, T.R. 1991. Butterfly Conservation. (Oxford University Press: Melbourne).
- QUICK, W.N.B. 1989. The Victorian 'Ant-blues' - *Acrodipsas* spp. (Lepidoptera: Lycaenidae). (Letter, Department of Conservation, Forests and Lands).

# COMPARISON OF ARTHROPOD SPECIES RICHNESS IN EASTERN AND WESTERN AUSTRALIAN CANOPIES: A CONTRIBUTION TO THE SPECIES NUMBER DEBATE

J.D. MAJER, H.F. RECHER AND A.C. POSTLE

Majer, J.D., Recher, H.F. & Postle, A.C. 1994 06 30: Comparison of arthropod species richness in eastern and western Australian canopies: a contribution to the species number debate. *Memoirs of the Queensland Museum* 36 (1): 121-131. Brisbane. ISSN 0079-8835.

Apart from forest pest species, our knowledge of *Eucalyptus* canopy arthropods is rudimentary. This has contributed to a lack of appreciation of the differences in arthropod abundances, biomass and richness on different species of eucalypts and in different forests throughout Australia. A three year chemical knockdown study has been carried out in one western Australian forest, where jarrah *Eucalyptus marginata* and marri *E. calophylla* were sampled and one eastern Australian forest, where narrow-leaved ironbark *E. crebra* and grey box *E. moluccana* were sampled. The arthropods from one year of sampling have been sorted to morphospecies. This paper documents the range of species found and compares arthropod species richness within orders and families and between the two forest types. Hymenoptera, Coleoptera, Diptera and Araneae were the richest in species. Nine hundred and seventy-seven species in 173 families were found in the eastern Australian forest, while 691 species in 176 families were found in the western Australian forest. Only 53% of families were common to both forests, but almost half the families recorded were represented by fewer than five species. Reasons for these patterns are briefly discussed and arthropod species richness in eucalypt communities is contrasted to that in other temperate and tropical forests. The implications of forest and land management practices for the conservation of arthropod richness are presented. □ *Invertebrates, insects, arthropods, forest, Eucalyptus, diversity.*

J. D. Majer & A. C. Postle, School of Environmental Biology, Curtin University of Technology, GPO Box U1987, Perth, WA 6001; H. F. Recher, Department of Ecosystem Management, University of New England, Armidale, NSW 2351; 12 July 1993.

Erwin's (1982) seminal paper on rainforest canopy invertebrates, which included the global estimate of 30 million arthropods, resulted in a steady flow of papers on canopy arthropods. Some supported Erwin's estimate and some regarded his figure as an overestimate (May, 1988; Stork, 1988; Gaston, 1991). To recapitulate, Erwin (1982) identified beetles from the canopy of one species of Panamanian tree. Then, using an estimate of the proportion of beetle species which were specific to individual tree species, the number of tropical tree species worldwide and the proportion of the total arthropod fauna represented by beetles, he extrapolated to provide an estimate of total arboreal arthropod species richness of 20 million. On the assumption that arthropod richness is twice as high in the canopy as on the ground, Erwin (1982) went on to estimate a global arthropod richness of 30 million species.

The assumptions on which Erwin based his estimates are subject to question. For instance, the degree of host specificity that Erwin assumed may not be correct (Gaston, 1991) and the proportion of key taxa in a sample may vary from community to community (e.g., Abbott et al., 1992; Kitching et al., 1993), thus leading to

problems in extrapolating from a single sample to provide global figures. Arthropod species richness in the canopy may not exceed that of the demonstrably rich soil and litter fauna and they may not be totally separate faunas (see, e.g., Adis, 1988; Hammond, 1990). A further problem with this debate is that most estimates are based upon samples taken in the rainforests; the implicit assumption is that most of the world's biological diversity occurs in the tropics. Clearly, if the conflict of opinion about global arthropod richness is to be sensibly resolved, we need reliable data on arthropod richness from temperate areas as well.

Australian *Eucalyptus* forests represent a vegetation type for which few data on arthropod richness exist. Eucalypt communities are of particular interest in relation to rainforests because they are evergreen and seasonal extremes in temperature are not as great as in temperate forests of the northern hemisphere. Thus, in terms of these features, they are intermediate between rainforests and temperate deciduous forests, which have had arthropod richness documented by a series of detailed investigations (e.g. Southwood et al., 1982a, 1982b; Erwin, 1983a, 1983b; Adis et al., 1984; Hijii, 1984; Stork, 1991). Im-

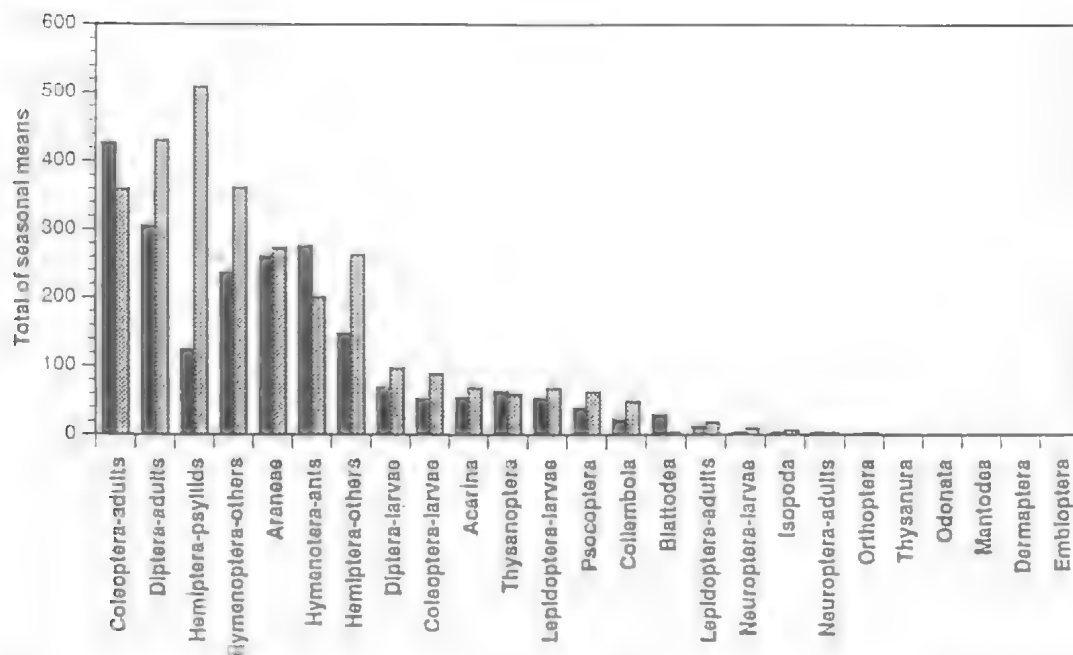


Fig. 1. Numbers of individuals in different arthropod orders on grey box (*E. moluccana*, black) and narrow-leaved ironbark (*E. crebra*, stippled). Values are mean arthropods per tree ( $n = 10$  trees) summed over the four seasons (Table 1).

portantly, eucalypt forests are dominated by a single genus, *Eucalyptus*, which in most habitats is represented by only a few species. Therefore, studies of eucalypt communities not only provide an opportunity to test predictions of global species richness but can be used to investigate various assumptions about the distribution of insect species between habitats and their degree of host specificity. The evergreenness of eucalypts, coupled with moderate seasonal changes in temperature and rainfall also allows an assessment of the contribution to species richness arising from temporal changes in community composition as distinct from spatial and habitat variation.

In 1985, we initiated studies in eucalypt forests on the relationship between arboreal invertebrate communities, foliage nutrient levels and tree species selection by foraging birds (Majer & Recher, 1988; Majer et al., 1990, 1992, in prep.; Recher et al., 1991, 1993; Recher & Majer, in press). Arboreal invertebrates were sampled seasonally on each of two species of eucalypts in a marri-jarrah forest in western Australia and a box-ironbark forest in eastern Australia. A subset of the samples has now been sorted to morphospecies. Here, we present a preliminary

analysis of the species richness of the arboreal invertebrate faunas in eucalypt forests. The numbers of species in the two forest types sampled are compared to the numbers reported for other forest communities. Subsequent papers will analyse the similarity of species composition between the eastern and western faunas, the extent of tree species specificity within each forest type, the variation in faunal composition within a tree species and the extent to which seasonal changes in community composition contribute to overall patterns of species richness.

## METHODS

Sampling was done seasonally from February 1987 through January 1988 at Scheyville, New South Wales (33°53'S, 150°51'E), where we sampled invertebrates on co-dominant narrow-leaved ironbark (*Eucalyptus crebra* F.Muell.) and grey box (*E. moluccana* Roxb.) and from April 1987 through November 1989 at Karragullen, Western Australia (32°04'S, 116°07'E) on co-dominant marri (*E. calophylla* R.Br. ex Lindley) and jarrah (*E. marginata* Donn. ex Smith). During each season, samples were taken from the canopy (>7 m) and subcanopy (<7 m).

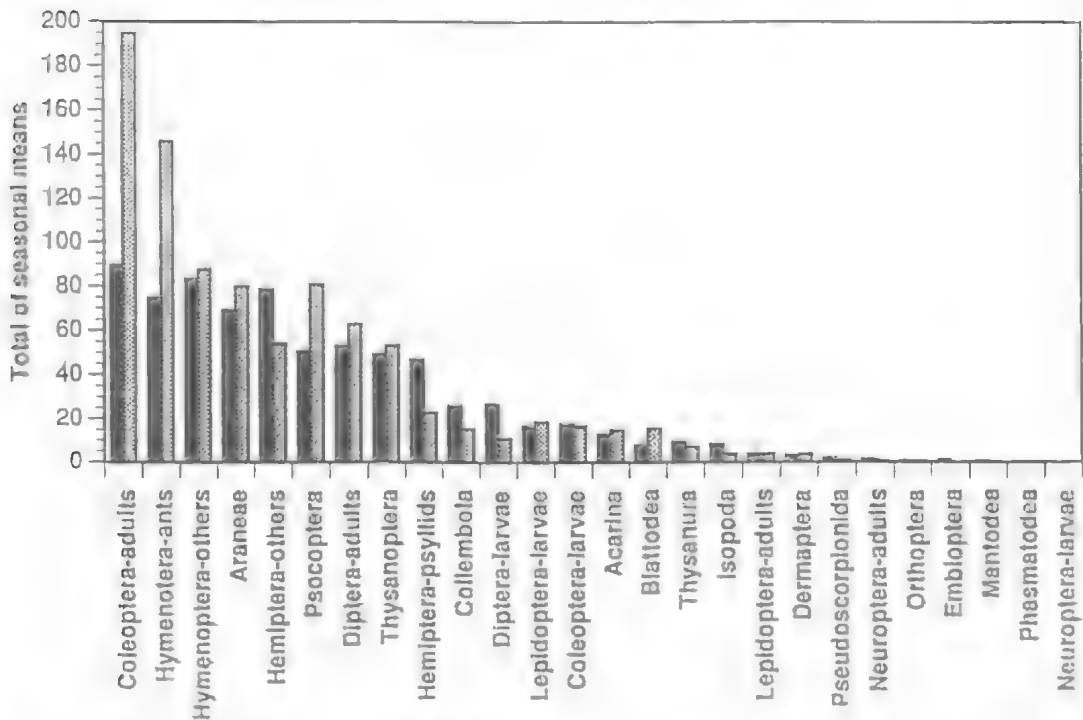


Fig. 2. Numbers of individuals in different arthropod orders on jarrah (*E. marginata*, black) and manri (*E. calophylla*, stippled). Values are mean arthropods per tree ( $n = 10$  trees) summed over the four seasons (Table 1.).

Because we were specifically interested in foliage-associated arthropods, we avoided sampling trees which were flowering.

Branch clipping and chemical knockdowns were used to sample invertebrates but only the data from material obtained by chemical knockdown are presented here. Details of the procedures used and the habitats sampled are presented in Majer & Recher (1988) and Majer et al. (1990, 1992). Briefly, in each season we selected 10 trees of each species and stratum for sampling. No tree was sampled more than once. Within each tree, we suspended ten  $0.5 \text{ m}^2$  funnel-shaped nets using a cherry-picker. Nets were positioned so as not to overlap and to sample all parts of the tree canopy. After a period of equilibrium (usually overnight), the trees were sprayed with a fast-acting pyrethrin insecticide synergised with piperonyl butoxide. Spraying was done only under calm conditions during early morning. Invertebrates collected by the nets were stored in 70% ethanol until sorted.

Limited time has allowed material only from the upper canopy samples and for the samples taken from April 1987 through January 1988 to be sorted to species (i.e. once for each season from autumn through summer in both States). The invertebrates were sorted initially to ordinal

level; resulting data were described in papers quoted above. Subsequently, except for the endopterygote larvae, the arthropods from each of the four seasons and four tree species were sorted to species. All animals were assigned to families and were labelled with code numbers for each species. Because of the taxonomic complexity of dealing with many juvenile spiders and of the extremely high richness of Hymenoptera, we sorted these two groups for the first two seasons only. In addition, because of the uncertainty in deciding whether individuals from eastern and western Australia were the same species, we used a separate numbering system for the material from the two areas. The putative species representatives are currently being sent to taxonomists in order to obtain generic and, where possible, specific names.

## RESULTS

Ordinal profiles derived from the numbers of arthropods collected in each taxon are presented for each tree species and for the two forests sampled (Figs. 1, 2). The current status of data-coding prevents segregation of arthropod species by tree species, so the number of species in each

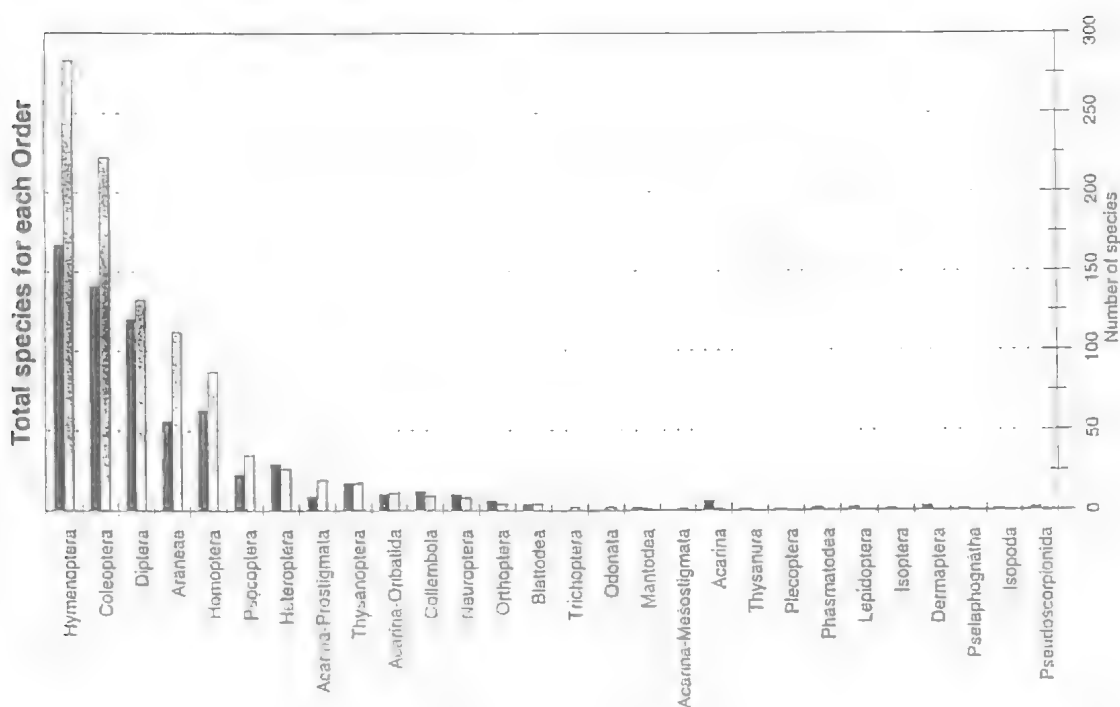


Fig. 3. Total number of species within each arthropod order sampled on 80 eastern Australian trees (*E. moluccana* and *E. crebra*, stippled) and 80 Western Australian trees (*E. marginata* and *E. calophylla*), black).

taxon can be compared between eastern and western Australia only.

A total of 67,400 individual arthropods were obtained from the 160 upper canopy trees sampled. Arthropods sampled numbered 50,900 in the eastern forest, but only 16,500 in the west. They were more abundant on narrow-leaved ironbark and grey box than on jarrah and marri in all seasons sampled (Table 1). Narrow-leaved ironbark supported consistently more arthropods than grey box and, apart from spring, their abundance was higher on marri than on jarrah. The most pronounced differences were in the many more psyllids, other Hemiptera, Diptera and Hymenoptera (excluding ants) on narrow-leaved ironbark and ants and adult Coleoptera on grey box (Fig. 1). Marri had many more adult Coleoptera, ants and Psocoptera than jarrah, while psyllids and other Hemiptera were more abundant on jarrah (Fig. 2).

#### ORDINAL PROFILES

Overall, arthropods from 23 orders of insects (Heteroptera and Homoptera counted as one order), arachnids and crustaceans were collected, with 20 sampled in western Australia and 17 in eastern Australia (Figs. 1, 2).

Hymenoptera, Hemiptera, Coleoptera, Diptera and Araneae were the most abundant orders of arthropods in both forests (Figs. 1, 2). These were followed by Psocoptera, Thysanoptera, Collembola, Lepidoptera and Acarina in that order in western Australia, and by Acarina, Thysanoptera, Lepidoptera, Psocoptera and Collembola in eastern Australia.

While there was some consistency in the ranked abundance of orders between eastern and western Australia, their relative abundance on different species of eucalypts was more variable. In Western Australia, Hymenoptera, Hemiptera, Coleoptera, Diptera, Araneae and Psocoptera in that order were the most abundant arthropods on jarrah, while Hymenoptera, Coleoptera, Psocoptera, Araneae, Hemiptera and Diptera were most abundant on marri. In eastern Australia, Hemiptera, Hymenoptera, Diptera, Coleoptera, Araneae and Lepidoptera in that order were most abundant on narrow-leaved ironbark. On grey box, Hymenoptera, Coleoptera, Diptera, Hemiptera, Araneae and Lepidoptera were most abundant.

#### SPECIES PROFILES

A total of 691 species of arthropod were identified from western Australia and 977 from east-

Tree Species	Season							
	Autumn 1987		Winter 1987		Spring 1987		Summer 1988	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grey box	411.40	48.68	416.10	38.20	605.50	92.09	742.00	118.28
Narrow-leaved ironbark	760.10	131.21	490.30	42.57	844.50	54.00	823.50	154.39
Jarrah	242.20	17.93	180.20	35.54	206.60	40.70	125.60	14.64
Marri	252.70	27.82	241.10	58.14	184.80	22.74	216.30	42.74

Table 1. Mean values (and standard deviation) of total number of arthropod individuals sampled per tree ( $n = 10$ )

ern Australia. Some species would undoubtedly be 'tourists' which have temporarily alighted or been carried onto the trees (e.g. the lycosid spider). Although the two reference collections have not yet been homologised, our knowledge of the material and early determinations from specialists indicate little overlap between the two faunas. The total number of arthropod species can conservatively be estimated to exceed 1500 species, of which some 1300 are insects.

A total of 229 families were encountered, of which 176 were represented in western Australia and 173 in eastern Australia (Table 2). Thus, although there are about 40% more species on eastern than on western Australian trees, the numbers of families in the two forests are relatively similar. There is a 53% overlap in the families sampled in the two forests, suggesting a high level of biological richness at family level. Forty-seven families represented in the eastern samples were absent in the west, while 56 families were sampled solely in the western Australian forest. Of the families which were confined to one particular forest, only four contained five or more species. Of the 229 families, 95 were represented by fewer than three species.

The total species within each order (Fig. 3) are ranked by the average of the amalgamated eastern and western Australian counts. The most diverse groups in both forests were the Hymenoptera (a total of 450 species), the Coleoptera (363) and Diptera (252), in that order. Araneae (168) and Homoptera (150) were the next richest taxa. The richness of species in Hymenoptera and Araneae is based on samples from two seasons and we estimate that their species richness would be 50% greater had the full set of samples been sorted. This does not alter the position of the Hymenoptera as the most species-rich taxon but could mean that the Araneae are the third most species-rich group. The numbers of species within each of the orders in the two forests were strongly correlated ( $r=0.98$ ,  $df=26$ ,  $p<0.001$ ). There were significant correlations between the number of individuals and of species within the various taxa ( $r=0.92$ ,

$df=18$ ,  $p<0.001$  for western Australia;  $r=0.91$ ,  $df=13$ ,  $p<0.001$  for eastern Australia).

Of the richest five orders, all were represented by more species in eastern Australia than in the west. The differences in species numbers were greatest among the Hymenoptera, with 283 species in eastern Australia and 167 in the west; the Coleoptera with 222 species versus 141; the Araneae with 112 species versus 56; and the Homoptera with 87 species versus 63. The Psocoptera with 35 species versus 23 was also substantially richer in the eastern than the western forest. Numbers of species in the less rich taxa exhibited broadly similar trends, with the only taxa having more species in western than eastern Australia being the Collembola, Heteroptera, Neuroptera and Orthoptera. The remaining taxa were represented by relatively few species, so the differences could well be an artifact of sampling. Thus, although generally more arthropod species were sampled in the eastern than the western forest, the inconsistent trends in the less speciose taxa meant that richness within order values between the two forests were not significantly different (paired  $t$ -test).

## DISCUSSION

The arthropods discussed here were sampled by chemical knockdown from 40 trees of each of two species in western and each of two species in eastern Australia. The work of Abbott et al. (1992), also performed in jarrah-marri forest, indicates that chemical knockdown samples only a part of the canopy fauna. The nets were hung near the extremities of branches of non-flowering trees, so animals collected were largely those associated with the foliage. The only exception to this amongst the most abundant elements of the fauna was the Psocoptera, which tend to be associated with the bark. Within eastern and western Australia respectively, these animals were most common on narrow-leaved ironbark and marri and, of the pairs of tree species in each

	WA	NSW		WA	NSW
CRUSTACEA			Trombidioidea		3
Isopoda	1		Acarina indet	6	1
ARACHNIDA			DIPLOPODA		
Pseudoscorpionida			Pselaphognatha	1	
Chernetidae	2		COLLEMBOLA		
Araneae			Brachystomellidae	1	1
Araneidae	14	32	Dicyrtomidae	1	1
Clubionidae	4	6	Entomobryidae	4	3
Corinnidae		2	Hypogastruridae		2
Ctenidae		1	Isotomidae	2	
Desidae		5	Neanuridae	1	
Gnaphosidae	2	2	Sminthuridae	3	2
Hahniidae		1	INSECTA		
Hersiliidae	1	1	Thysanura		
Heteropodidae	2	2	Lepismatidae	1	
Linyphiidae	1	1	Odonata		
Lycosidae	1		Coenagrionidae		1
Micropholcommatidae	1		Lestidae		1
Oxyopidae		2	Plecoptera		
Pararchaeidae	1		Gripopterygidae	1	
Philodromidae		1	Orthoptera		
Salticidae	9	19	Gryllacrididae	2	2
Segestrinidae	1		Gryllidae	2	
Tetragnathidae		2	Tettigoniidae	2	2
Theridiidae	9	14	Blattodea		
Thomisidae	5	7	Blattellidae	4	3
indet.	5	14	Blattidae		1
Acarina-Mesostigmata			Isoptera		
Phytoseiidae		1	Rhinotermitidae	1	
Acarina-Oribatida			Dermaptera		
Ceratozetoidea	2		Pygidicranidae	3	
Cymbaeremaeidae	1		Phasmatodea		
?Cymbaeremaeoidea		4	Phasmatidae	2	
Oribatulidae		1	Mantodea		
Oribatuloidea	1	5	Amorphoscelidae	1	
Plaueremaeidae	1		Mantidae	1	
Plateremaeidae	4		Psocoptera		
indet.	1	1	Caeciliidae		2
Acarina-Prostigmata			Ectopsocidae	2	3
Anystidae	2	5	Elipsocidae	2	1
?Anystidae		1	Lepidopsocidae	1	1
Bdellidae	2	2	Myopsocidae	1	1
Erythraeoidea	3	8	Peripsocidae	2	1
?Erythraeoidea	1		Philotarsidae	7	7
Oribatuloidea		1	Pseudocaeciliidae	1	5

Table 2. Numbers of species found within various arthropod families sampled from trees in a western and an eastern Australian forest.



Table 2. continued

	WA	NSW
Psocidae	3	4
indet.	4	10
Homoptera		
Achilidae		2
Aleyrodidae	2	1
Aphididae	5	3
Aphrophoridae	1	
Cercopidae	2	
Cicadellidae	17	34
Cicadidae		2
Cixiidae	2	1
Coccoidea	2	
Eurybrachyidae	2	1
Eurymelidae	4	2
Flatidae	2	3
Machaerotidae	4	3
Membracidae	2	1
Psyllidae	16	36
Heteroptera		
Alydidae	2	
Anthocoridae	3	3
Ceratocombidae	2	1
Lygaeidae	2	3
Miridae	7	15
Pentatomidae	6	3
Reduviidae	3	1
Thaumastocoridae	2	
Tingidae	2	
Thysanoptera		
Aelothripidae	3	4
Phlaeothripidae	6	10
Thripidae	8	3
Neuroptera		
Chrysopidae	2	1
Coniopterygidae	3	3
Hemerobiidae	2	1
Mantispidae	2	3
Myrmeleontidae	1	
Lepidoptera		
Yponomeutidae	1	
indet.	1	
Trichoptera		
Leptoceridae		2
Diptera		
Agromyzidae		1

	WA	NSW
Anisopodidae	1	1
Anthomyzidae		1
Asilidae		1
Aulacigastridae		1
Bombyliidae	1	
Calliphoridae	1	1
Cecidomyiidae	4	10
Ceratopogonidae	9	9
Chamaemyiidae	2	1
Chironomidae	11	7
Chloropidae	15	24
Chyromyidae		1
Cryptochaetidae		2
Dolichopodidae	3	4
Drosophilidae	5	4
Empididae	17	9
Ephydriidae	3	1
Fergusoninidae	1	2
Heleomyzidae	1	
Lauxaniidae	3	7
Longchaeidae		1
Milichiidae	2	2
Muscidae	3	7
Mycetophilidae	6	4
Phoridae	3	8
Pipunculidae	1	
Platystomatidae	1	
Pseudopomyzidae	1	
Psychodidae	1	1
Scatopsidae	1	1
Sciaridae	6	5
Sepsidae	1	3
Simuliidae	2	
Stratiomyidae	3	
Syrphidae	2	1
Tabanidae	1	1
Tachinidae	2	5
Therevidae	2	1
Tipulidae	1	2
indet.	7	
Coleoptera		
Aderidae	1	1
Alleculidae	3	3
Anobiidae	3	9
Anthicidae	2	
Anthribidae		1
Attelabidae	2	8

Table 2. continued

	WA	NSW
Belidae	1	3
Bostrichidae		1
Buprestidae	3	3
Cantharidae	2	10
Carabidae	5	9
Cerambycidae		5
Chrysomelidae	12	30
Ciidae	1	1
Cleridae	5	6
Coccinellidae	9	18
Colydiidae		2
Corylophidae	2	3
Cryptophagidae	2	2
Cucujidae	1	
Curculionidae	37	43
Dascillidae	2	
Dermestidae	2	5
Dytiscidae		1
Elateridae		5
Endomychidae	1	
Endomychidae ?		1
Histeridae	2	1
Hydraenidae		1
Laemophloeidae	3	
Lagriidae		1
Lathridiidae	3	2
Leiodidae	1	
Melandryidae	1	2
Melyridae		5
Mordellidae		2
Mycetophagidae		1
Nitidulidae	2	2
Oedemeridae	1	
Phalacridae		1
Phloeostichidae		1
Pselaphidae	2	
Ptiliidae	1	1
Pythidae		1
Salpingidae	3	2
Scarabaeidae	7	6
Scraphiidae	2	1
Scydmaenidae	1	

	WA	NSW
Silvanidae	1	2
Spercheidae		1
Staphylinidae	4	9
Tenebrionidae	7	7
Throscidae	1	
Trogossitidae		1
Zopheridae	1	
indet.	4	
Hymenoptera		
Anthophoridae	1	
Aphelinidae	9	9
Apidae	3	
Bethylidae	7	4
Braconidae	14	31
Ceraphronidae	4	1
Chalcidae	2	
Charipidae		1
Colletidae	1	
Diapriidae		1
Dryinidae		1
Elasmidae		1
Encyrtidae	16	60
Eulophidae	32	43
Eupelmidae	5	4
Eurytomidae	3	3
Figitidae	1	
Formicidae	22	33
Ichneumonidae		4
Megaspilidae	1	
Myrmecidae	2	13
Pergidae	1	5
Platygasteridae	6	18
Pompilidae	1	
Pteromalidae	18	26
Scelionidae	3	10
Sphecidae	4	3
Thysanidae	1	
Tiphiidae	1	
Torymidae	5	4
Trichogrammatidae		2
Vespidae		1
indet.	4	5
Total families	176	173
Total species	691	977

area, these are the ones which retain a thick bark layer on their branches.

As well as species associated with bark (J. Monaghan, pers. comm.), flowers, fruits and the wood of trees, there is also that component of the biota associated with other tree species, with the shrubs and with the soil and litter layer. These parts of the ecosystem also support a rich arthropod fauna in these two areas of Australia. For instance, Postle et al. (1991) sampled the soil and litter arthropods in jarrah-marti forest at Dwellingup, some 50 km south of Karragullen and found 290 animal species in nine small sample plots. Thus, the total arthropod species richness for our two sample sites is a conservative estimate; the actual total would be considerably higher than the figure we obtained.

The high correlation between the ordinal and species profiles indicates that the former provides some reflection of the species richness of a sample or a site. Indeed, our finding that species richness is far higher in the eastern than the western forest had already been alluded to by the substantially higher abundance of arthropods in the eastern than the western site (Majer et al., 1990, in prep.; Recher et al., 1991). The reason for this difference between forests has not yet been conclusively found. However, Majer et al. (1992) found substantially higher levels of foliar nitrogen and phosphorus in the eastern than in the western Australian trees and, by referring to other trends in foliar nutrients between tree species and within tree canopies, suggested that the abundance of arthropods might be a response to nutrient levels. If this is the case, the differences may well apply to eastern and western Australia as a whole.

Reasons for the high richness of arthropods in these two forests is not here discussed. The degree of host plant specificity (Fox & Morrow, 1981) and also the geographical range of the host plant (Strong, 1979) could be contributory factors but the data have not yet been processed to the extent required to investigate this aspect of eucalypt-associated invertebrates. This paper aims only to introduce a planned series of papers on arthropod community structure in *Eucalyptus* forest canopies. However, one immediately evident component of richness is the, as yet unanalysed, seasonal variation in community composition. This component of richness has generally been overlooked by canopy workers, most of whom base their richness counts on a single season of sampling. It was evident from our samples that each season which we sorted

always yielded a considerable number of additional species and that this seasonal turnover was a major factor contributing to the high species richness in our samples. We believe that this is an important component of diversity which needs to be considered in future studies and that it is important enough to be considered as a separate component of diversity. We refer to this new component as sigma ( $\sigma$ ) diversity.

Using current estimates of between 108,000 and 145,000 species of Australian insects (Taylor, 1983; Nielsen & West, in press), our samples represent some 0.9-1.2% of the total Australian insect fauna. We sampled only four of the 600 or so Australian eucalypt species, sampled only the canopy and sampled only from two extremely localised sites. We thus feel that it is unlikely that we have sampled as great a percentage as this of the Australian insect fauna. This leaves us with no other conclusion than that the number of Australian insect species has been grossly underestimated.

Our figures for arthropod species richness are intermediate between the high values for the canopy of tropical forests (Erwin, 1982, 1983b; Stork, 1987; Basset & Arnhington, 1992) and the much lower values for deciduous temperate forests (Southwood et al., 1982a, 1982b). Most contributions to the debate on global arthropod species richness are based on data obtained from the tropics. Limited consideration is given to data from temperate forests. Our data support the statement that Australia is one of the 12 megadiverse countries that together account for 75% of the total biodiversity of the planet (McNeely et al., 1992) and concur with Platnick's (1991) statement that more attention should be given to the temperate regions when estimating global biodiversity. If this were done, it is likely that current estimates of arthropod species richness would be elevated to even higher levels.

The richness of the canopy arthropod fauna from only two sites and four species of eucalypts confirms the need to include a consideration of invertebrates when planning and managing conservation reserves. The 1500 or so species which we sampled represent only part of the invertebrate species richness of the forests where we worked.

There were no *a priori* reasons for expecting either site to have a rich canopy invertebrate fauna. Neither forest has a floristically diverse or complex structured canopy. Five species of eucalypt occur on the Scheyville site and four at Karragullen but the two eucalypts sampled on

each area dominate the canopy (>90% of foliage) and understorey vegetation. Both forests have a long history of disturbance (e.g., logging, changed fire regimes and, in the case of Scheyville, grazing) and occur on relatively poor soils. Scheyville retains a diverse, albeit depleted avifauna (>70 breeding bird species) (H.F. Recher, unpublished data) and prior to European settlement would have had a rich mammal fauna (Recher & Hutchings, 1993). Jarrah forest, of the type represented at Karragullen, has a relatively poor avifauna (about 45 breeding bird species) (H.F. Recher, unpublished data), a feature which is typical of dry, open eucalypt forests.

The Karragullen site is part of a Western Australian State Forest which is managed by the government for timber and firewood production and, as such, is relatively secure from development. As one of the largest remaining fragments of an originally extensive woodland on the Cumberland Plain, Scheyville has been proposed for nature reserve status since the late 1960's. It is also Crown Land (i.e. government owned) but only a small part has been reserved and the remainder has been proposed for development as a housing estate. Failure to reserve the entire area is in part a failure to appreciate the biological richness and in part a consequence of a paradigm that emphasises large, predominantly natural or wild areas with little economic value for nature conservation. Such attitudes do not consider the possibility that invertebrate communities may persist relatively intact or at least retain high species richness, regardless of a history of disturbance and habitat fragmentation. The diversity of the flora and the number of vertebrate species may also not be good predictors of invertebrate species richness. This is particularly so if historical changes to the flora and vertebrate fauna are not considered.

The richness and abundance of canopy arthropods at Scheyville and Karragullen are compelling arguments for the use of broader criteria when planning and managing conservation reserves. Areas such as Scheyville that represent the only remaining fragments of formerly extensive habitats, may retain most of the original fauna, although much of the vertebrate fauna may have become extinct. As such, these areas have considerable conservation value regardless of their size and the lack of wilderness values. The management of more extensive habitats, such as that at Karragullen, needs to consider how management practices, for example prescription

burning, affect the whole fauna rather than just the vertebrate fauna.

## ACKNOWLEDGEMENTS

This project was undertaken by means of a grant from the Australian Research Council. We would also like to thank the many taxonomic specialists who have helped or who are currently helping us with the determination of species. Dr Robert Floyd and Philip Groom kindly assisted with the data base and graphical analyses.

## LITERATURE CITED

- ABBOTT, I., BURBIDGE, T., WILLIAMS, M. & VAN HEURCK, P. 1992. Arthropod fauna of jarrah (*Eucalyptus marginata*) foliage in mediterranean forest of Western Australia: spatial and temporal variation in abundance, biomass, guild structure and species composition. *Australian Journal of Ecology* 17: 263-274.
- ADIS, J. 1988. On the abundance and density of terrestrial arthropods in Central Amazonian dryland forests. *Journal of Tropical Ecology* 4: 19-24.
- ADIS, J., LUBIN, Y.D. & MONTGOMERY, G.G. 1984. Arthropods from the canopy of inundated and terra firme forests near Manaus, Brazil, with critical considerations on the pyrethrum fogging technique. *Studies on Neotropical Fauna and the Environment* 19: 223-236.
- BASSET, Y. & ARTHINGTON, A.H. 1992. The arthropod community of an Australian rainforest tree: Abundance of component taxa, species richness and guild structure. *Australian Journal of Ecology* 17: 89-98.
- ERWIN, T.L. 1982. Tropical forests. Their richness in Coleoptera and other species. *Coleopterists Bulletin* 36: 74-75.
- 1983a. Tropical forest canopies: the last biotic frontier. *Bulletin of the Entomological Society of America* 30: 14-19.
- 1983b. Beetles and other insects of tropical forest canopies at Manaus, Brazil, sampled by insecticidal fogging. In Sutton S.L., Whitmore, T.C. & Chadwick, A.C. (eds) 'Tropical rain forests: Ecology and management' pp 59-75. (Blackwell Scientific Publications: Oxford).
- FOX, L.R. & MORROW, P.A. 1981. Specialisation: species property or local phenomenon? *Science* 211: 887-893.
- GASTON, K.J. 1991. The magnitude of global insect species richness. *Conservation Biology* 5: 282-296.
- HAMMOND, P.M. 1990. Insect abundance and diversity in the Dumoga-Bone National Park, N. Sulawesi, with special reference to the beetle fauna of lowland dry forest of the Torant region. In Knight, W.J. & Holloway, J.D. (eds) 'Insects and rain forests of south east Asia (Wallacea)' pp

- 197-254. (Royal Entomological Society of London, London).
- HILL, N. 1984. Arboreal arthropod fauna in a forest II. Presumed community structures based on biomass and number of arthropods in a *Chamaecyparis obtusa* plantation. Japanese Journal of Ecology 34: 187-193.
- KITCHING, R.L., BERGELSON, J.M., LOWMAN, M.D., MCINTIRE, S. & CARRUTHERS, G. 1993. The biodiversity of arthropods from Australian rainforest canopies: general introduction, methods, sites and ordinal results. Australian Journal of Ecology 18: 181-191.
- MAJER, J.D. & RECHER, H.F. 1988. Invertebrate communities on Western Australian eucalypts: a comparison of branch clipping and chemical knockdown procedures. Australian Journal of Ecology 13: 269-278.
- MAJER, J.D., RECHER, H.F. & GANESHANANDAM, S. 1992. Variation in foliar nutrients in Eucalyptus trees in eastern and western Australia. Australian Journal of Ecology 17: 383-393.
- MAJER, J.D., RECHER, H.F., PERRIMAN, W.S. & ACHUTHAN, N. 1990. Spatial variation of invertebrate abundance within the canopies of two Australian eucalypt forests. Studies in Avian Biology 13: 65-72.
- MAY, R.M. 1988. How many species are there on earth? Science 241: 1441-1449.
- MCNEELEY, J.A., MILLER, K.R., REID, W.V., MITTERMEIR, R.A. & WERNER, T. 1992. 'Conserving the World's Biological Diversity' (National Academy Press: Washington, DC).
- NIELSEN, E.S. & WEST, J.G. (in press). Biodiversity research and biological collections: transfer of information. In Forey, P. (ed.) 'Systematics and conservation evaluation' (Oxford University Press: Oxford).
- PLATNICK, N.I. 1991. Patterns of biodiversity: tropical vs temperate. Journal of Natural History 25: 1083-1088.
- POSTLE, A.C., MAJER, J.D. & BELL, D.T. 1991. A survey of selected soil and litter invertebrate species from the northern jarrah (*Eucalyptus marginata*) forest of Western Australia, with particular reference to soil-type, stratum, seasonality and the conservation of forest fauna. In Lunney, D. (ed.) 'Conservation of Australia's forest fauna' pp 193-203. (Royal Zoological Society of NSW: Mosman).
- RECHER, H.F. & HUTCHINGS, P.A. 1993. The biota of the Hawkesbury-Nepean catchment: Historical reconstruction and restoration. Australian Zoologist 29: 3-41.
- RECHER, H.F. & MAJER, J.D. (in press). On the selection of tree species by Australian warblers (Acanthizidae) in open-forest near Sydney, New South Wales. Emu.
- RECHER, H.F., MAJER, J.D., & FORD, H.A. 1991. Temporal and spatial variation in the abundance of eucalypt canopy invertebrates: the response of forest birds. Acta XX Congress Internationalis Ornithologici. 1568-1575.
- RECHER, H.F., MAJER, J.D., GOWING, G. & SARTI, N.L. 1993. Canopy invertebrate communities in woodlands - a comparison of morning and afternoon samples by chemical knockdown. Mulga Research Centre Journal 11: 26-29.
- SOUTHWOOD, T.R. E., MORAN, V.C. & KENNEDY, C.E. J. 1982a. The richness, abundance and biomass of the arthropod communities on trees. Journal of Animal Ecology 51: 635-649.
- 1982b. The assessment of arboreal insect fauna - comparison of knockdown sampling and faunal lists. Ecological Entomology 7: 331-340.
- STORK, N.E. 1987. Guild structure of arthropods from Bornean rain forest trees. Ecological Entomology 12: 69-80.
1988. Insect diversity: facts, fiction and speculation. Biological Journal of the Linnean Society 35: 321-337.
1991. The composition of the arthropod fauna of Bornean lowland rain forest trees. Journal of Tropical Ecology 7: 161-180.
- STRONG, D.R. 1979. Biogeographic dynamics of insect-host plant communities. Annual Review of Entomology 24: 89-119.
- TAYLOR, R.W. T. 1983. Descriptive taxonomy: past, present and future. In Higley, E. & Taylor, R.W. T. (eds) pp. 93-134. 'Australian systematic entomology: A Bicentenary perspective' (C.S.I.R.O., Melbourne).

# PHOTOGRAPHIC IDENTIFICATION OF STREAM MACRO-FAUNA: A MINIMALLY DESTRUCTIVE SAMPLING TECHNIQUE.

*Memoirs of the Queensland Museum* 36(1): 132. 1994:—

Sampling of streams typically involves the removal and preservation of fauna for subsequent identification and enumeration in the laboratory (e.g. Storey et al., 1990). Such methods, however, might not be appropriate in studies of temporal changes in small stream communities because they alter the composition of the communities under investigation. Observed differences in subsequent samples may therefore reflect changes precipitated by earlier sampling activity as well as natural alterations in community structure.

The following method has been developed to identify and enumerate stream macro-fauna from photographs, permitting animals to be released alive after photography. A search of the literature did not reveal any references to this method of sampling stream macro-fauna.

Live specimens are picked from associated debris by hand, placed in a white perspex tray (measuring 14.5 × 10 cm with clear perspex sides 2 cm high), covered with water and photographed. The base of the tray has been roughened to reduce reflections and a small scale bar glued to one side to permit measurement of animals. An SLR camera fitted with 50 mm lens and 12 mm extension ring is loaded with ISO 50/188 transparency film. This lens combination produces an image magnification of × 0.25 at which the specimen tray fills the field of view. A small cross in the centre of the tray permits rapid alignment and focusing. Illumination is by two electronic flash guns (Guide Number 15 m @ ISO 100) mounted on small tripods, one at approximately 20 cm from either end of the tray and aimed at its centre. One flash is synchronised to the camera's shutter via its coaxial socket by a synchronising cable, while the second is automatically discharged by a built-in photovoltaic slave cell when the first is fired. Exposure is calculated with an electronic flash meter. An aperture half a stop larger than indicated is used to compensate for the light-reducing effect of the extension ring.

Photographic transparencies of the samples are later

projected onto sheets of white paper for identification and enumeration of the fauna. At times, to aid identification, it is necessary to view some transparencies under a dissecting microscope with sub-stage illumination.

Photographic sampling is being used to study temporal changes in the macro-fauna of pools in small rainforest streams. Photographs of animals from several habitats at twelve sites in two streams are taken monthly. Examples of species that have not previously been encountered, or that are difficult to identify, are preserved for later comparison with voucher specimens. Thus sampling is not totally without effect on the community, but it is considerably less destructive than it would be if all animals were killed.

Taxonomic resolution obtainable from photographed samples is often not as high as can be achieved from conventional preserved samples. This obstacle is considerably reduced when the fauna studied is well known and a reference collection of preserved specimens is available for comparison with photographed specimens. In the present study, for example, 64 of the 78 taxa recorded (82%) can be identified to species from photographs and most of the remainder can be identified to genus or family. However, the photographic sampling method is not suitable for samples where the animals are not readily separated from associated debris.

## Acknowledgements

Thanks to Stuart Bunn, Ngaire Phillips and Marty Kahoonu Hancock for suggestions and encouragement.

## Literature cited

Storey, A.W., Bunn, S.E., Davies, P.M. & Edward, D.H. 1990. Classification of the macroinvertebrate fauna of two river systems in Southwestern Australia in relation to physical and chemical parameters. *Regulated Rivers: Research & Management* 5: 217-232.

Jonathan C. Marshall, Faculty of Environmental Sciences,  
Griffith University, Nathan, Queensland 4111, Australia;  
16 July 1993.

# FAUNAL BREAKS IN TASMANIA AND THEIR SIGNIFICANCE FOR INVERTEBRATE CONSERVATION

ROBERT MESIBOV

Mesibov, R. 1994 06 30: Faunal breaks in Tasmania and their significance for invertebrate conservation. *Memoirs of the Queensland Museum* 36(1): 133-136. Brisbane. ISSN 0079-8835.

Faunal breaks are narrow landscape zones in which invertebrate species assemblages change more or less abruptly. At least three faunal breaks are found on the main island of Tasmania, each coincident with an ecotone which may act as a dispersal barrier. It is argued that faunal breaks need to be conserved for their value in reconstructing the historical zoogeography of a wide range of invertebrate taxa. □ Conservation, invertebrates, parapatry, Tasmania, zoogeography.

Robert Mesibov, P.O. Box 700, Burnie, Tasmania 7320, Australia; 11 May 1994.

'Tasmania itself, regarded from a zoogeographical point of view, is not a single homogeneous unit.' (Smith, 1909: 145)

Although regional variation in the Tasmanian fauna has long been recognised (see epigraph), it has only recently become apparent that regional changes in species assemblages can occur over relatively short distances and involve a broad range of taxa. Such localised changes are here called 'faunal breaks'. This paper briefly summarises current knowledge of faunal breaks in Tasmania and proposes directions for their further study and conservation.

## EXAMPLES

### TYLER'S LINE

The name 'Tyler's Line' was given by Shiel et al. (1989) to the eastern range boundary of a rotifer species assemblage in western Tasmania. The eponymous Peter Tyler has pointed out that the line is more than a limnological divide; it is 'a congruence of climatic, geologic, edaphic and vegetational change' (Tyler, 1992: 358). Solid and dashed lines (Fig. 1) are parapatric boundaries between (a) the grasshoppers *Russalpia albertis* (Bolivar 1898) (east) and *R. longifurca* Key, 1991 (west), after Key (1991); (b) the frogs *Litoria burrowsi* (Scott, 1942) (west) and *L. raniformis* (Keferstein, 1867) (east), after Martin & Littlejohn (1982) and unpublished records (P. Brown, pers. comm. and T. Kingston, pers. comm.) and (c) the freshwater decapods *Astacopsis franklinii* (Gray, 1845) (east) and *A. tricornis* Clark, 1936 (west), after Hamr (1992). Dotted lines are eastern boundaries of (d) the terrestrial amphipod *Neorchestia plicibranchia* after Friend (1987), and (e) the grasshopper *Truganinia*

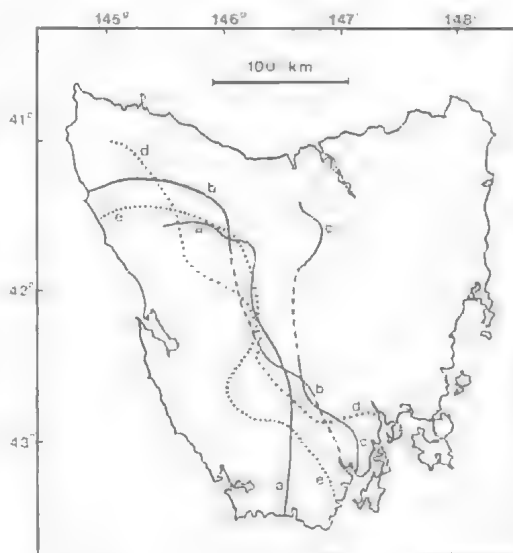


Fig. 1. Tyler's Line. See text for explanation.

*baueri*, after Key (1991). Less complete distribution data suggest that Tyler's Line is respected by land snails (Smith & Kershaw, 1981; e.g. *Mulathena fordei* (Brazier, 1871), *Victaphanta milligani* (Pfeiffer, 1853)), caddis flies (Neboiss, 1981; e.g. *Ecnomus russellius* Neboiss, 1977, *Plectrocnemia manicata* Neboiss, 1977, *Triplectides bilobus* Neboiss, 1977), skinks (Rawlinson, 1974, and Hutchinson et al., 1989; e.g. the apparently parapatric *Niveoscincus microlepidotus* (O'Shaughnessy, 1874) and *N. ocellatus* (Gray, 1845) and freshwater decapods of *Parastacoides* (A. Richardson, pers. comm.).

### PLOMLEY'S ISLAND AND ENVIRONS

Two dalodesmid millipede species, *Lissodesmus alisonae* Jeckel, 1984 (triangles) and *Lis-*



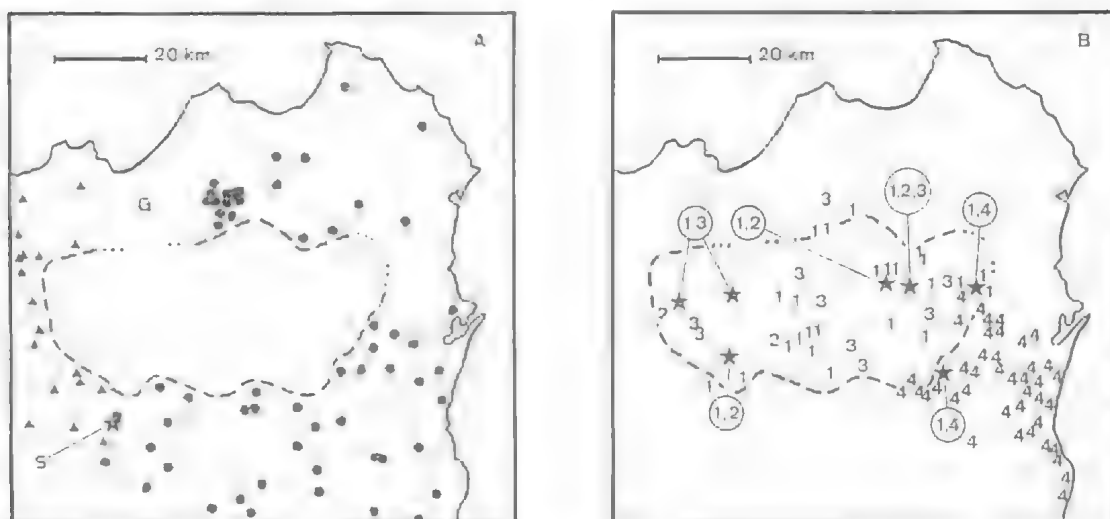


FIG. 2A, B. Plomley's Island. See text for explanation.

*sodesmus* n. sp. E1 (dots), are parapatric and co-occur at the site 'S' (Fig. 2A; from Mesibov, 1993). Neither species is known in area 'G', here called Bridport Gap, which coincides with the western range boundary of another dalodesmid, *Lissodesmus* n.sp. NE5 (Mesibov, 1993).

The 'hole' in combined distributions of *L. alisonae* and *L. n.sp. E1* (see dashed line Fig. 2), contains nearly all known localities of three unrelated invertebrates (Fig. 2B): (1) the land snail *Anoglypta launcestonensis* (Reeve, 1853) (after Kershaw, 1988), (2) the geophilomorph centipede *Tasmanophilus* sp. (records as used in Mesibov, 1986) and (3) the dalodesmid millipede *Gasterogramma* n.sp. 5 (Mesibov, 1993). The oblong area (dashed line, Fig. 2) is here called Plomley's Island, after the late historian, N.J.B. Plomley, who has for many years encouraged natural history studies in northeast Tasmania. The eastern 'edge' of Plomley's Island is here called Gould's Country Break. It coincides with western range boundaries of the onychophoran *Tasmanipatus barretti* Ruhberg et al., 1991 (localities marked '4' in Fig. 2B, after Mesibov & Ruhberg, 1991 and Mesibov, unpublished records) and apparently the terrestrial amphipod *Keratroides pyrensis* Friend, 1987, as well as the eastern range boundary of *Lissodesmus adrianae* Jeekel, 1984 (Mesibov, 1993). East Tamar Break on the western 'edge' of Plomley's Island appears to coincide with eastern range boundaries for the dalodesmids *Gasterogramma psi* Jeekel, 1982 and *Tasmanodesmus hardyi* Chamberlin, 1920 and western range boundaries for *Lissodesmus*

*adrianae* and *L. n.sp. NE1* (Mesibov, 1993). Western and eastern faunal breaks on the boundary of Plomley's Island thus involve at least eight and seven species, respectively, from five invertebrate groups: amphipods, centipedes, millipedes, onychophorans and snails.

#### OTHER FAUNAL BREAKS

There is limited evidence for nine other faunal breaks on the main island of Tasmania, including the Bridport Gap referred to above (Mesibov, unpublished data). Several 'breaks' may be relatively diffuse (up to 30km wide), while others may involve only the few species so far known to respect them. I regard these possible breaks as zoogeographical hypotheses to be tested by future fine scale mapping of a range of taxa.

#### ORIGINS

Faunal breaks in Tasmania generally correspond with ecotones. Environmental gradients along portions of Tyler's Line, for example, are demonstrably steep (Tyler, 1992), as are altitudinal gradients on the east and west 'edges' of Plomley's Island. An ecotone at a faunal break might mark the distribution limit of habitats preferred by break-respecting species, and in the case of parapatric species pairs, ecotonal change might facilitate parapatry caused by other mechanisms (Bull, 1991). However, for slow-dispersing invertebrates (e.g. millipedes and land snails), an ecotone may represent a dispersal barrier, with ample suitable habitat on the other side.

Some invertebrates respecting a faunal break are limited by barriers, others by habitat. Parapatric species pairs are also a problematic feature of faunal breaks. To paraphrase Key (1991), while a steep environmental gradient may have determined the location of a faunal break involving parapatry, it may not have been responsible for its existence. In the grasshopper *Russalpia* (see Fig. 1), Key (1991) proposed that the common ancestor of *R. albertisi* and *R. longifurca* was distributed widely enough for two populations to have been reproductively isolated by an intervening barrier. This barrier may have been ice-covered and periglacial high country of central Tasmania during Pleistocene glacial maxima. 'Following the spread of warmer conditions at c. 7000 B.P., one or both of the now differentiated populations could have spread into the formerly glacial areas until they met and produced the [hybrid] tension zone. This in turn may have moved westward or eastward to reach its present position.' (Key, 1991: 286). Alternatively, *Russalpia* may have speciated sympatrically or parapatrically at Tyler's Line ecotone during non-glacial times. More generally, the more congeneric species pairs at a faunal break, the more likely that the break is located near a past barrier responsible for allopatric speciation, or at an ecotone responsible for sympatric or parapatric speciation. Faunal breaks thus offer insights into evolutionary history, and phylogenetic analysis might reveal the sequence in which sets of barriers or ecotones were operative in the evolution of the taxa.

### CONSERVATION

If faunal breaks divided Tasmania into discrete zoogeographical units, then a simple basis would be available for planning future sampling effort and for proposing regionally representative fauna reserves. Unfortunately, Tasmania is far from being a neat zoogeographical mosaic. Even if careful mapping of invertebrate distributions allowed us to draw 'consensus' boundaries for Tasmanian zoogeographical provinces, the usefulness of such provinces for conservation purposes would be compromised by the fact that many invertebrates, e.g. megascolecid earthworms (Jamieson, 1974; T. Kingston, pers. comm.), have very restricted distributions. High priorities would have to be assigned to such species within today's taxon-focussed conservation paradigm, yet geographically restricted invertebrates stand outside any system of

provinces. A more significant concern is that individual faunal boundaries may involve only a fraction of the local fauna. What level of local endemism would justify the division of Tasmania into faunal provinces? The threshold would have to be well above the 'noise level' for invertebrate distribution data. As Buzas et al. (1982) and Koch (1987) have shown, the typical pattern of invertebrate species abundances, namely the Fisher log series, gives rise to false absences in sampling with a disconcertingly high probability. For example, a large group of invertebrate samples was shown to exhibit a unique species proportion of 25% in comparison with an equal number of samples drawn later from precisely the same data set of species occurrences (Koch, 1987).

The problem is illustrated by the Tasmanian Trichoptera records of Neboiss (1981). Distribution maps for 163 species were presented showing occurrences in seven proposed faunal provinces on the main island. If the provinces are grouped into 'west of Tyler's Line' (northwest + southwest) and 'east of Tyler's Line' (north + northeast + east + southeast + central), then the two resulting superprovinces have about the same number of trichopteran species: 133 in the west, 125 in the east. The proportion of eastern species which are unique to that superprovince is only 24%, and more than half the unique species were recorded from only one or two localities. Such one- or two-site species might actually be widespread and uncommon, rather than geographically restricted. Neboiss et al. (1989) later reported that four of the 30 'uniquely eastern' species had since been found in southwest Tasmania (namely *Costora seposita* Neboiss, 1977, previously known from one eastern site; *Hydroptila tasmanica* Mosely, 1934, from one; *Oecetis laustra* Mosely, 1953, from one; and *Orphnino-trichia acta* Neboiss, 1977, from two). It is likely that percentage differences in species lists across any of Tasmania's faunal breaks would be at the level expected from random sampling of a uniformly distributed fauna (vide Koch, 1987). Faunal breaks are demonstrable, but faunal provinces may not be.

### DISCUSSION

Recognition of faunal breaks, together with recent fine scale mapping of geographically restricted invertebrates (e.g. Horwitz, 1991; Mesibov & Ruhberg, 1991; and Taylor, 1991), has shown that invertebrate sampling in Tas-

mania needs to be carefully planned on a geographical basis. The main island is intricately regionalised and it is unwise to assume that invertebrate species are distributed more than a few km from known localities. It is also becoming clear that faunal breaks are potentially rich sources of information on the historical zoogeography of Tasmania and the evolution of its invertebrate fauna. For this reason I suggest that faunal breaks need to be protected, both from destruction by habitat clearance and from faunal impoverishment through ill-considered land use. There is more valuable zoological information to be conserved along a faunal break, even where habitats have been disturbed, than in a 'pristine' or little modified tract of native vegetation well within a faunally homogeneous area.

#### ACKNOWLEDGEMENTS

Millipede mapping by the author has been supported by the Plomley Foundation through the Queen Victoria Museum and Art Gallery (QVMAG). For unpublished Litoria records I thank Peter Brown of the Tasmanian Parks and Wildlife Service and Tim Kingston, QVMAG. A draft of this paper was substantially improved by the suggestions of Peter McQuillan and Alastair Richardson.

#### LITERATURE CITED

- BULL, C.M. 1991. Ecology of parapatric distributions. *Annual Review of Ecology and Systematics* 22: 19-36.
- BUZAS, M.A., KOCH, C.F., CULVER, S.J. & SOHL, N.F. 1982. On the distribution of species occurrence. *Paleobiology* 8: 143-150.
- FRIEND, J.A. 1987. The terrestrial amphipods (Amphipoda: Talitridae) of Tasmania: systematics and zoogeography. *Records of the Australian Museum Supplement* 7: 1-85.
- HAMR, P. 1992. A revision of the Tasmanian freshwater crayfish genus *Astacopsis* Huxley (Decapoda: Parastacidae). *Papers and Proceedings of the Royal Society of Tasmania* 126: 91-94.
- HORWITZ, P. 1991. 'The Conservation Biology of *Engaeus spinicaudatus*, a Threatened Crayfish from North-Eastern Tasmania'. (Unpublished report for the Australian National Parks and Wildlife Service).
- HUTCHINSON, M.N., ROBERTSON, P. & RAWLINSON, P.A. 1989. Redescription and ecology of the endemic Tasmanian scincid lizards *Leiopisma microlepidotum* and *L. pretiosum*. *Papers and Proceedings of the Royal Society of Tasmania* 123: 257-274.
- JAMIESON, B.G.M. 1974. The zoogeography and evolution of Tasmanian Oligochaeta. Pp. 195-228. In Williams, W.D. (ed.), 'Biogeography and Ecology in Tasmania'. (Dr. W. Junk: The Hague).
- KERSHAW, R.C. 1988. A study of the Caryodidae (Pulmonata). Part 1. *Anoglypta launcestonensis* (Reeve 1853). *Records of the Queen Victoria Museum* 93: 1-24.
- KEY, K.H.L. 1991. On four endemic genera of Tasmanian Acrididae (Orthoptera). *Invertebrate Taxonomy* 5: 241-288.
- KOCH, C.F. 1987. Prediction of sample size effects on the measured temporal and geographic distribution patterns of species. *Paleobiology* 13: 100-107.
- MARTIN, A.A. & LITTLEJOHN, M.J. 1982. 'Tasmanian Amphibians. Fauna of Tasmania Handbook No. 6'. (Fauna of Tasmania Committee, University of Tasmania: Hobart).
- MESIBOV, B. 1986. 'A Guide to Tasmanian Centipedes'. (B. Mesibov: Hobart).
1993. 'Millipede Studies in Northeast Tasmania'. (Unpublished report for the Plomley Foundation).
- MESIBOV, R. & RUHBERG, H. 1991. Ecology and conservation of *Tasmanipatus barretti* and *T. anophthalmus*, parapatric onychophorans (Onychophora: Peripatopsidae) from northeastern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 125: 11-16.
- NEBOISS, A. 1981. 'Tasmanian Caddis-flies. Fauna of Tasmania Handbook No. 4'. (Fauna of Tasmania Committee, University of Tasmania, Hobart).
- NEBOISS, A., JACKSON, J. & WALKER, K. 1989. Caddis-flies (Insecta: Trichoptera) of the World Heritage Area in Tasmania: species composition and distribution. *Occasional Papers from the Museum of Victoria* 4: 1-41.
- RAWLINSON, P.A. 1974. Biogeography and ecology of the reptiles of Tasmania and the Bass Strait area. Pp. 291-338. In Williams, W.D. (ed.), 'Biogeography and Ecology in Tasmania'. (Dr. W. Junk: The Hague).
- SHIEL, R.J., KOSTE, W. & TAN, L.W. 1989. Tasmania revisited: rotifer communities and habitat heterogeneity. *Hydrobiologia* 186/187: 239-245.
- SMITH, B.J. & KERSHAW, R.C. 1981. 'Tasmanian Land and Freshwater Molluscs. Fauna of Tasmania Handbook No. 5'. (Fauna of Tasmania Committee, University of Tasmania: Hobart).
- SMITH, G. 1909. 'A Naturalist in Tasmania'. (Clarendon Press: Oxford).
- TAYLOR, R.J. 1991. Distribution and habitat of *Helicarion rubicundus* (Pulmonata: Helicariidae), a rare land snail. *Papers and Proceedings of the Royal Society of Tasmania* 125: 27-28.
- TYLER, P.A. 1992. A lakeland from the dreamtime. The second Founder's Lecture. *British Phycological Journal* 27: 353-368.

## TARDIGRADES OF THE AUSTRALIAN ANTARCTIC TERRITORIES: ASSESSING DIVERSITY WITHIN A SAMPLE

W.R. MILLER, J.D. MILLER AND H.F. HEATWOLE

Miller, W.R., Miller, J.D. & Heatwole, H.F. 1994 06 30: Tardigrades of the Australian Antarctic Territories: assessing diversity within a sample. *Memoirs of the Queensland Museum* 36(1): 137-145. Brisbane. ISSN 0079-8835.

A 10 × 10 × 5 cm sample was collected from a moss bed near Casey Station in the Australian Antarctic Territory and analysed as a series of 27 subsamples, which were reassembled in layers and columns to examine the distribution of tardigrades in the original sample. Three genera containing four species of tardigrades were recovered from the subsamples: *Diphascon chilense*, *Pseudechiniscus suillus*, *Hypsibius antarcticus* and *D. pinguis*. Tardigrades were not evenly distributed horizontally or vertically; nor did a strong association occur among the species. The results indicate that although small diameter core samples minimise damage to fragile moss beds in harsh climatic areas such as the Antarctic, single samples do not necessarily provide an accurate assessment of the distribution or diversity present. □ Australia, Antarctic, biodiversity, Tardigrada, sampling, ecology, taxonomy.

W.R. Miller, Department of Zoology, University of New England, Armidale 2351, N.S.W., Australia; J.D. Miller, Queensland Department of Environment & Heritage, PO Box 5391, Townsville 4810, Queensland, Australia; H.F. Heatwole, Department of Zoology, North Carolina State University, Raleigh, North Carolina, U.S.A.; 2 August 1993.

The terrestrial ecosystems of continental East Antarctica are confined to small areas of unfrozen coast and to nunataks that protrude through the ice (Holdgate, 1967). These 'islands' (sensu Miller et al., 1988), situated in a sea of mostly frozen water, exhibit a rudimentary soil that is inhabited by bacteria, yeasts, fungi, unicellular algae, rotifers, nematodes, tardigrades and mites (Heatwole, 1983; Heatwole et al., 1989). A few species of lichens and mosses grow on this soil and the surrounding rocks (Lamb, 1970); as the primary flora, the lichens and mosses harbour an assortment of microscopic plants and animals.

Because of the extreme conditions under which Antarctic mosses grow (Greene & Longton, 1970; Lamb, 1970), they form micro-environmental units that can be destroyed by disruption (Opalinski, 1972). As a result of very slow growth rates (Longton & MacIver, 1974), recovery following disruption or sampling might require years (Seppelt & Ashton, 1978) even in less extreme climates such as southern Australia (Scott & Stone, 1976). Obviously, minimal sampling is required to prevent destruction of the moss bed. However, a conflict occurs between the need to not disrupt the internal environmental conditions required for growth, and the need to sample enough of the moss to provide a representative collection of the micro-organisms that inhabit it.

The qualitative method used for sampling micro-fauna inhabiting moss beds is commonly called a 'grab' sample because the dimensions are

not defined or are only poorly defined. This type of sampling has been used in broad-based surveys and/or systematic studies and has commonly included multiple samples taken from relatively small areas (e.g. Riggan, 1962; Morgan & King, 1976; Nelson & Homing, 1979; Homing et al., 1978; Dastych, 1984). Although 'grab' samples may be useful in the context of a survey to assess the number of species present, without multiple samples the assessment may be an underestimate. Because they are of unknown size and volume, 'grab' samples can not be used to estimate population size, density, biomass (Jennings, 1976a) or distribution within the sample.

The use of small diameter or square core samples (e.g. Hallas, 1975; Jennings, 1976a; Miller et al., 1988; Miller et al., 1994) seems to satisfy the need to obtain regular quantitative samples; however, the use of only a few cores to assess the species diversity in a moss turf carries with it the assumption that the core sample is representative of the microfauna and flora inhabiting the larger floral unit. The use of pooled cores, 3 or more small diameter cores, taken a few centimetres apart and combined to form a composite sample has been used (Jennings, 1976a) to satisfy some of the statistical requirements of representing the larger environment. Contiguous square samples (2 × 2 × 0.5 cm) have been used to assess the distribution of tardigrades in relation to the micro-environment of the moss turf (Hallas, 1975). Although curing is a very useful sampling

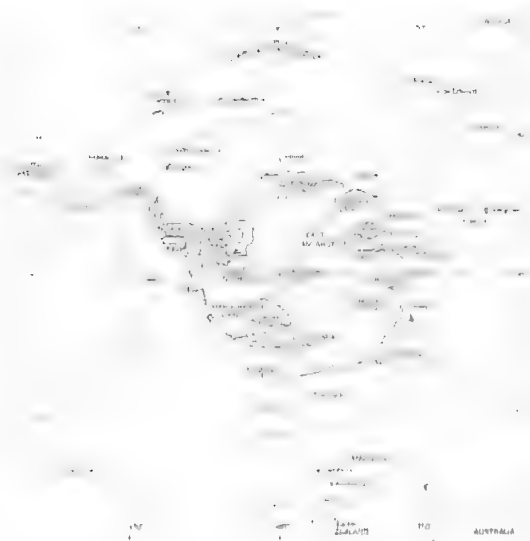


FIG. 1. Location map showing the relative positions of Australia and Casey Station.

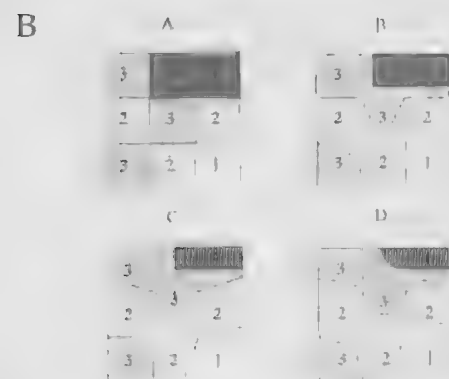
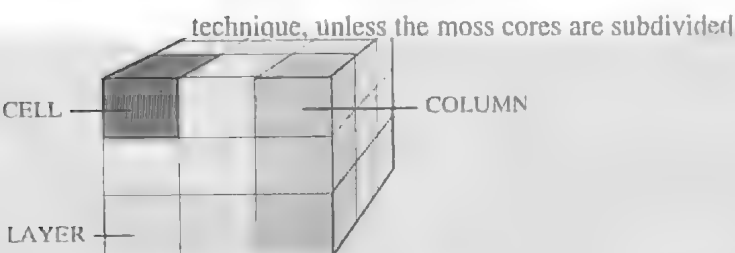


FIG. 2. A. Terminology used for describing parts of the 10x10x5cm sample of Antarctic moss. B. Illustration of the process of smoothing used in constructing the distributional patterns of four species of tardigrades inhabiting the volumetric sample of Antarctic moss. Top face of sample is illustrated; numbers indicate the number of species in each column (see text for details).

zero during the middle of the day but regularly drop below freezing at night. The average temperature in December is 2.2°C (Bureau of Meteorology, 1988).

## METHODS

Field work was done during the austral summer program of the Australian National Antarctic Research Expeditions (ANARE) in December 1982. The sample analysed here was collected as a part of a general survey of the study area (Miller et al. unpub data).

A single 10 cm square was cut from the moss bed to the depth of the underlying substrate (approximately 5 cm). The resulting sample was removed and immediately divided into three layers (each approximately 1.6cm thick); each layer was subdivided into nine small cells (approximately 3.3x3.3x1.6cm). Each cell was dried in an individual paper bag at room temperature. The process of preparation of the specimens

A

into two or more layers, the vertical distribution of tardigrade numbers or species in the sample can not be addressed.

The purpose of the present study was to determine the distributional patterns of tardigrade numbers and species within a single volumetric sample of Antarctic moss. The sample was analysed according to the hypotheses of (1) uniform distribution for numbers of tardigrades, (2) even diversity of species, and (3) equal association among the species.

## STUDY AREA

The sample was taken from an unsheltered site below a melt-water lake near the new Casey Station (66°17'S, 110°32'E) on the Bailey Peninsula in Wilkes Land, East Antarctica (Fig. 1). The ocean side of the area (Vincennes Bay) is dotted with the low, rocky Windmill islands. To the east is the Loken Moraine, which marks the limit of the exposed rock. To the north is the Clark Peninsula where the abandoned Wilkes Base is located. To the immediate south of Casey Station is the Mitchell Peninsula; further south is Browning Peninsula and the Vanderford Glacier. Throughout the area, patches of seasonally exposed rock are separated by permanent ice fields. A few exposed areas exceed two hectares in size; however, most are much smaller. In the summer, air temperatures may rise several degrees above

and slides was described by Miller et al. (1988). The distribution of tardigrades within the total sample was determined by combining the results obtained from analysis of individual cells into layers and columns (Fig. 2A). Assessment of species diversity was based on the presence or absence of a species in each of the cells; determination of the inter-specific association among the species was based on the expected joint occurrence of each pair of species. Statistical analysis followed Zar (1984) and Miller et al. (1994).

A three-dimensional model based on the number of species found in each cell was constructed to represent the distribution of the tardigrade species within the total sample (Fig. 2B). The initial construction of the model assumed that the cells were discrete units containing specific numbers of tardigrade species. The boundaries between cells were smoothed to form polygons representing the potential patterns of distribution of the species based on two assumptions: (1) that a cell with a large number of species would contain areas occupied by fewer species (i.e. assuming an uneven distribution of species within the cell) and (2) that a cell with a low number of species could not contain an area occupied by a higher number of species. After a distributional pattern was developed for each face of the sample, the model was drawn in 3-D perspective.

## RESULTS

At the time of collection, the moss turf was on a well drained gravel/stone substrate. The moss was green in the upper portion of the first layer only; the lower portion of the first layer and the two lower layers appeared brown. There was more plant litter in the bottom layer than in the two upper layers.

The only moss species found in the sample was *Bryum argenteum* Hedwig, 1801, a moss that grows in densely tufted cushions. *B. argenteum* has reddish-brown stems that are matted with simple radicles, erect leaves that are oblong and concave, and yellow-green to green leaves that are reddish at the base. The nerve of the leaf is well defined and reddish-brown in colour; under magnification the cells of the leaf are an irregular rhomboid-hexagonal shape. *B. argenteum* is known from Syowa (Tatuno, 1963), the Vestfold Hills (Seppelt, 1984), Casey Base (Seppelt & Selkirk, 1984) and is considered a cosmopolitan moss (Longton, 1981).

Three genera containing four species of tar-

	<i>Diphascon chilense</i>	<i>Pseudechiniscus suillus</i>	<i>Hypsibius antarcticus</i>	<i>Diphascon pinguis</i>	TOTAL (Percent)
I	740 (47.2)	43 (2.7)	31 (2.1)	5 (0.3)	819 (52.2)
TAXONIC (Percent)	540 (33.1)	4 (0.3)	2 (0.1)	0 (0.0)	551 (35.1)
II	198 (12.6)	0 (0.0)	0 (0.0)	0 (0.0)	198 (12.6)
TOTAL (Percent)	1478 (94.3)	52 (3.3)	33 (2.1)	5 (0.3)	1568 (100.0)

FIG. 3. Distribution by layer of four species of tardigrades recovered from a 10 × 10 × 5 cm sample of Antarctic moss.

digrades were represented in the 1568 specimens recovered from the total sample. A taxonomic account of these is given in Dastych (1984). They are listed below in order of relative abundance in the total sample:

*Diphascon chilense langhovdensis* (Sudzuki, 1964): 1478 specimens or 94.3%.

*Pseudechiniscus suillus* (Ehrenberg, 1853): 52 specimens (3.3%).

*Hypsibius antarcticus* (Richters, 1904): 33 specimens (2.1%).

*Diphascon pinguis* (Marcus, 1936): 5 specimens (0.3%). *D. pinguis* is known from King George Island (Dastych, 1984), South Shetland Island and South Georgia (Jennings, 1976a, b), but not before from East Antarctica.

All 27 cells of the sample contained at least one species of tardigrade (*D. chilense*), 8 cells (29.6%) contained two species (*D. chilense*, and *P. suillus*), 3 cells (11.1%) contained three species (*D. chilense*, *P. suillus* and *H. antarcticus*) and 2 cells (7.4%) contained all four species (Table 1). Two or more species were represented in 48.1% of the cells and three or more occurred in 18%. The actual number of animals (regardless of species) in a cell ranged from 0 to 158 (Table 1). There was a significant departure from the hypothesis of even distribution ( $\chi^2$  {p=0.05=38.89, 26}=923.37), indicating that the tardigrades did not occur uniformly among the cells of the moss sample. When considered separately, the distribution of *D. chilense*, which occurred in all cells, was not even ( $\chi^2$  {p=0.05=38.89, 26}=888.28) among the cells.

When the cells were combined to form the three layers of the original sample (Fig. 3), 819 of the 1568 specimens (52.2%) were recovered from the top layer, 551 (35.1%) from the second layer, and

TABLE 1. Distribution of tardigrade species by cell from a 10×10×5 cm sample of Antarctic moss.

*Diphascon chilense*

	Column									Total
Layer	1	2	3	4	5	6	7	8	9	
I	73	135	46	50	64	65	114	158	35	740
II	24	39	42	141	41	47	125	67	14	540
III	10	24	40	42	36	9	8	12	17	198
Total	107	198	128	233	141	121	247	237	66	1478

*Pseudechiniscus suillus*

	Column									Total
Layer	1	2	3	4	5	6	7	8	9	
I	3	3	1	2	5	13	11	5	0	43
II	3	2	1	3	0	0	0	0	0	9
III	0	0	0	0	0	0	0	0	0	0
Total	6	5	2	5	5	13	11	5	0	52

*Hypsibius antarcticus*

	Column									Total
Layer	1	2	3	4	5	6	7	8	9	
I	2	2	26	0	1	0	0	0	0	31
II	0	1	0	0	0	0	1	0	0	2
III	0	0	0	0	0	0	0	0	0	0
Total	2	3	26	0	1	0	1	0	0	33

*Diphascon pinguis*

	Column									Total
Layer	1	2	3	4	5	6	7	8	9	
I	0	3	2	0	0	0	0	0	0	5
II	0	0	0	0	0	0	0	0	0	0
III	0	0	0	0	0	0	0	0	0	0
Total	0	3	2	0	0	0	0	0	0	5

198 (12.7%) from the bottom layer. *D. chilense* was found in all layers in contrast to *D. pinguis*, which was found only in the top layer; the other two species, *H. antarcticus* & *P. suillus*, were found in layers I and II but not in layer III. Based on the total number of tardigrades in each layer, there was a significant departure from the hypothesis of even distribution among the layers ( $\chi^2$  {p0.05= 5.99, 2}= 371.2), indicating that tardigrades did not occur uniformly among the layers. Although *D. chilense* was found in all three layers, its distribution was not even ( $\chi^2$  {p0.05= 5.99, 2}= 292.6) among the layers.

When the cells were combined to form nine vertical columns (Table 2), *D. chilense* was

found in all columns; *P. suillus* was recovered from 8 columns. *H. antarcticus* occurred in 5 columns and *D. pinguis* was collected from only 2 columns. Based on the total number of tardigrades in each column, there was a significant departure from the hypothesis of even distribution among the columns ( $\chi^2$  {p0.05= 15.51, 8}= 200.34), indicating that the tardigrades did not occur uniformly among the columns. The distribution of *D. chilense*, the only species found in all columns, was uneven ( $\chi^2$  {p0.05= 15.51, 8}= 204.12) among the columns.

In terms of assessing species diversity and distribution of tardigrades within a moss bed, the subsampling of the 10×10×5cm sample



TABLE 2. Distribution of tardigrades in columns of a  $10 \times 10 \times 5$  cm sample of Antarctic moss. In each box, number in square identifies column; large number indicates the number of species; small numbers indicate the number of individuals from each species. Percentage is based on the total for each column and the total number (1568) of tardigrades.

Species			Species		
1	115	7.3%	4	209	13.3%
3	115	7.3%	4	209	13.3%
2	141	9.0%	5	147	9.4%
4	243	15.5%	3	243	15.5%
5	247	15.8%	2	243	15.5%
6	121	7.7%	1	243	15.5%
7	11	0.7%	8	243	15.5%
8	11	0.7%	9	243	15.5%
9	11	0.7%			

provides instructive results. Assuming that a subsample would be taken from only one of the nine columns (Fig. 2, Table 2), only two (22.2%) of the 9 columns that could be sampled would have contained all 4 species; another three (33.3%) would have contained three species. Of the remaining four columns, three (33.3%) would have yielded only two of the four species present in the total sample and the last (11.1%) would have revealed only one. There was an 88.8% chance that a single column taken from the total would not contain all four species that actually inhabited the sample.

The greatest number of species did not occur in the columns with the greatest number of specimens (Table 2). Three contiguous columns (4, 7, 8) (Table 2) contained (47.1%) of all specimens recovered; however none of these contained all four species. Both columns 2 and 3 contained four species but only 23.5% of the total number of specimens combined (13.4%, 10.1%, respectively). Columns in which three species occurred ranged from a low of 7.3% of the total number of individuals to a high of 16.5%. Three columns, each containing 2 species, yielded 8.6%, 15.5% and 15.2% percent of the total, respectively. The column that contained only one species did contain the fewest individuals.

When the three layers and nine columns were considered together (Fig. 3, Table 1, 2), there was a clear vertical trend of decreasing numbers of *D. chilense* with depth into the moss sample. In 7

of the nine columns, layer I contained more specimens than layer II; in 2 columns, layer II contained the most *D. chilense*. In 8 of the 9 columns, layer II contained more specimens than layer III. In one column, layer III contained more *D. chilense* than layer II but only by 3 individuals.

Fifty-two *Pseudechiniscus suillus* were recovered from 12 cells (44.4%) from 8 columns of the total sample. Most specimens (43) were recovered from layer I; the remaining 9 were recovered from layer II. None were found in the bottom layer.

The total sample contained 33 specimens of *Hypsibius antarcticus* in 6 cells (11.2%). Most (31) were recovered from layer I; the remaining 2 were recovered from layer II. None were found in layer III. All except 2 specimens occurred in columns 1, 2 and 3.

Five *Diphascon pinguis* were found in 2 cells (7.4%) of contiguous columns (2, 3); all were found in layer I.

Within the  $10 \times 10 \times 5$  cm sample, the four species occurred together in only 2 columns (Table 2). The three species (*D. chilense*, *P. suillus* & *H. antarcticus*) occurred together in 3 columns; the two species (*D. chilense* & *P. suillus*) occurred together in 3 columns. One species (*D. chilense*) occurred alone in one

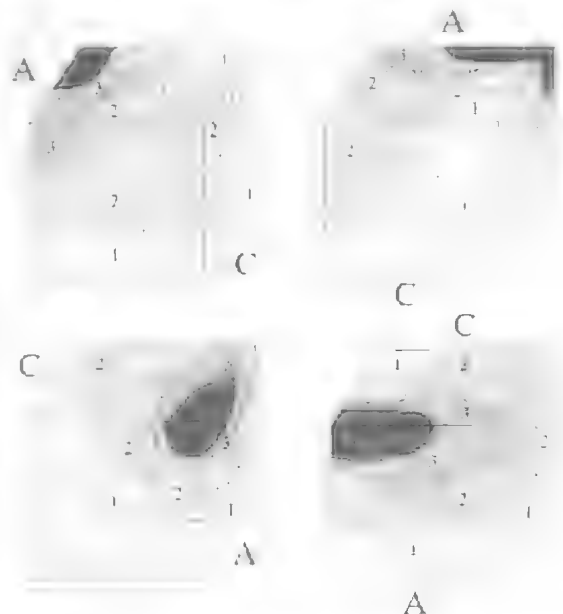


FIG. 4. Three dimensional model representing the distribution of four species tardigrades in a  $10 \times 10 \times 5$  cm sample of Antarctic moss.

TABLE 3. Inter-specific association based on the expected pattern of joint occurrence within cells between pairs of tardigrade species recovered from a 10 × 10 × 5cm sample of Antarctic moss.

Species × Species	LAYERS			COLUMNS			CELLS		
	P=0.05 expected	$\chi^2=5.99$ observed	df=2 $\chi^2$	P=0.05 expected	$\chi^2=15.51$ observed	df=8 $\chi^2$	P=0.05 expected	$\chi^2=38.89$ observed	df=26 $\chi^2$
<i>D. chilense</i> × <i>P. suillus</i>	2.00	2.00	0	8.00	8.00	0	12.00	12.00	0
<i>D. chilense</i> × <i>H. antarcticus</i>	2.00	2.00	0	5.00	5.00	0	6.00	6.00	0
<i>D. chilense</i> × <i>D. pinguis</i>	1.00	1.00	0	2.00	2.00	0	2.00	2.00	0
<i>P. suillus</i> × <i>H. antarcticus</i>	2.00	2.00	0	3.56	4.00	0.90	2.67	5.00	4.73
<i>P. suillus</i> × <i>D. pinguis</i>	0.67	1.00	0.75	1.78	2.00	0.32	0.89	2.00	2.70
<i>H. antarcticus</i> × <i>D. pinguis</i>	0.67	1.00	0.75	1.11	2.00	2.06	0.44	2.00	7.56

column. The least common species, *D. pinguis*, occurred only in the columns with the greatest diversity of species; it never was found alone or just with other infrequently occurring species.

However,  $\chi^2$  analysis for inter-specific association between species-pairs of tardigrades exhibited no great departure from the expected numbers of joint occurrences based on the numbers of the species within the cells and established that the tardigrades were not highly associated or disassociated (Table 3).

The smoothing of the boundaries between contiguous cells based on the number of species present in each and the rotation of the 3 dimensional model allow inferences to be made concerning the distribution of the species within the sample (Fig. 4). There was an increasing gradient from the bottom to the top of the sample and from one side to the other. The irregularly shaped pattern of distribution of the species extends beyond the boundaries of the sample and is probably controlled by factors outside the sample. The analysis of inter-specific association among the tardigrades suggests that they probably respond more to variations in the micro-environment of the sample than to each other. The complexity of the distribution of the tardigrades can be demonstrated by comparing the pattern shown in Fig. 2B to that depicted in Fig. 4. Three species are recorded in the lower left corner of Fig. 2B (which represents the total for column 7) but not in column 7 of the 3-D model (Fig. 4) because the three species do not occur together in any one cell of the column.

#### DISCUSSION

Many species of Antarctic tardigrades are

widely distributed (McInnes, 1994); others have restricted distributions (Miller et al., 1988; Dasytch, 1984, 1989). For example, the distribution of *Pseudechiniscus suillus* is relatively well known; it has been reported from the Antarctic as well as at least 8 separate land-masses and oceanic islands. In contrast, the distributions of *Diphascon chilense* and *Hypsibius antarcticus* are incompletely known; this probably reflects the distribution of collecting effort more than the actual distribution of the species. A good example of the process of range extension is the expansion of the known distribution of *Diphascon pinguis* to include Casey Station in East Antarctica. Without doubt, as more collections are analysed further extensions in range will occur.

At the level of the collection site, tardigrades are known to be unevenly distributed through the habitat and do not necessarily occur in every sample (e.g. Hallas, 1975, 1977; Schuster & Grigarick, 1970; Miller et al., 1988). Reconstruction analysis of the distribution of tardigrades within the 10 × 10 × 5cm sample confirms the previous observations and indicates that the tardigrades were not uniformly distributed among the layers. The tardigrades were concentrated in the uppermost layers of the sample, probably in response to the same environmental conditions of the Antarctic summer that effect the moss, including moisture, temperature and light (Greene & Longton, 1970; Lamb, 1970; Seppelt & Ashton, 1984). Moisture may be the most important factor influencing the distribution of the tardigrades in the sample (Hallas, 1975); but the presence of food may also be an influence.

After analysing 66 contiguous 2 × 2cm square samples that were between 0.5 and 0.8cm thick, Hallas (1975) pooled the species to view the

distribution of the numbers of tardigrades because one species represented 91% of the 368 specimens recovered. His results (Hallas, 1975: fig 2) show an uneven distribution of 1-13 individuals per square that is very similar to the pattern shown in Table 2 (i.e. greater numbers of individuals in some areas and fewer in other areas). The concentration (based on biomass) of the tardigrades in the uppermost portion of the moss cushion where most of the moisture was situated (Hallas, 1975) is reflected in the highest numbers being found in the upper layer of the  $10 \times 10 \times 5$  cm sample (Table 1).

While neither the number of animals nor the number of species was evenly distributed within the total sample, the species occurred independently of each other (i.e. one species did not occur more frequently with another than would be expected). Yet, each species seems to be more concentrated in one area of the total sample (Table 1). *D. chilense* is concentrated in columns 4, 7 and 8 while *D. pinguis* is concentrated in columns 2 and 3 as is *H. antarcticus*. *P. suillus* exhibits a broader, uneven distribution with some concentration in columns 6 and 7 of the sample. It is interesting to note that the greatest number of species did not occur in the columns or cells that contained the greatest number of specimens.

The skewed pattern of distribution of the tardigrade species toward the upper layer and to one side of the sample suggests that there may be unsampled areas of the moss turf where a fifth species may exist. Conversely, the paucity in both numbers and species of tardigrades in the opposite corner of the total sample suggests that some unsampled parts of the moss turf may be unoccupied by tardigrades.

Qualitative 'grab' samples may provide a measure of diversity but should be avoided because the undefined size of the sample precludes rigorous comparison with other samples and because any structure or pattern of distribution of the micro-fauna within the sample is lost. In contrast, small diameter core samples can provide quantitative information not only on the species composition, but also on relative abundance and patterns of association. For example, Jennings (1976a, b) used 3.5 cm diameter (by 3.0 cm depth) cores, where possible, to create a volumetric measure on which to base his population-density and bio-mass estimates. Most of the core samples were analysed in total; some were pooled to create bulk samples from which aliquots were drawn for analysis. Unfortunately, 'information on the

spatial dispersion of the population is lost' (Jennings, 1976a) using these techniques. It should be noted that Jennings was concerned with differences in population structure and species richness between sites and not within sample distribution.

Hallas (1975) noted that obtaining information on the vertical distribution of species would be 'advantageous' to understanding the ecology of tardigrades. Information on the vertical distribution can be obtained by dividing cores into at least two (upper & lower) subsamples and is necessary to understand the patterns of association of the species inhabiting the sample. For example, analysis of column 7 without dividing it into layers yielded 3 species but when the distribution within the column was considered, two species (*D. chilense* and *P. suillus*) occurred in the top layer, and a different combination of species (*D. chilense* and *H. antarcticus*) occurred in the middle layer, and only one species (*D. chilense*) occupied the bottom layer. This sort of result may eventually lead to an understanding of the distribution, patterns of association and response to environmental conditions.

Unless numerous cores are taken, the use of small diameter cores may not adequately sample the diversity of species within the moss turf. In the present study, there was only a 2 in 9 chance of collecting all four tardigrade species from the  $10 \times 10 \times 5$  cm sample using the columns as cores. Clearly, if too sparse of a sampling pattern were imposed on the uneven distribution of tardigrade species in a moss turf, the result would be an underestimation of the species richness. However, the use of multiple cores to obtain samples from even a small area, increases the probability of accurately determining the species richness in the moss turf and of identifying real differences between areas. For example, using multiple cores to sample moss turfs on Signy Island, Jennings (1976a) found 16 tardigrade species at 43 sites but only 9 (21%) of those sites yielded more than 3 species. Likewise, he found 11 species at 70 sites on the Antarctic Peninsula and Scotia Ridge region, but only 7 (10%) had more than 3 species (Jennings, 1976b). These results approximate the results of analysing one or two columns of the  $10 \times 10 \times 5$  cm sample without dividing them into layers. Obviously, the collection of multiple small diameter core samples from moss beds is necessary to accurately sample the diversity of the tardigrade inhabitants.

Based on the analysis of this  $10 \times 10 \times 5$  cm sample, tardigrade distribution within an Antarctic moss sample is complex with both num-

bers and species being unevenly distributed horizontally and vertically. The analysis also illustrates the need to base the collection of moss samples on good sampling design to allow statistical analysis of the results. Multiple small diameter cores should be used to assess the microfauna inhabiting moss beds; the sampling practice should also ensure only minimal damage occurs to the moss turf.

#### ACKNOWLEDGMENTS

We are grateful to the Australian National Antarctic Research Expeditions (ANARE) and to the personnel of the Australian Antarctic Division, especially those at Casey Station. Other logistical support was financed by the Ian Potter Foundation and by Internal Research Grants from the University of New England, Armidale. N.S.W. Dr H. Dastyh, University of Hamburg kindly confirmed the identifications of the tardigrades.

#### LITERATURE CITED

- BUREAU OF METEOROLOGY 1988, 'Climatic averages Australia', (Australian Government Publishing Service: Canberra).
- DASTYCH, H. 1984. The Tardigrada from Antarctic with descriptions of several new species. *Acta Zoologica Cracoviensia* 27: 377-436.
1989. An annotated list of Tardigrada from the Antarctic. *Entomologische Mitteilungen aus dem Zoologischen Museum Hamburg* 9: 249-257.
- EHRENBERG, C.G. 1853. *Diagnoses novarum furmarum*. Berlin, Bericht 1853: 526-533.
- GREENE, S.W. & LONGTON, R.E. 1970. The effects of climate on Antarctic plants. Pp. 786-800. In Holdgate, M.W. (ed.), 'Antarctic ecology' Vol II. (Scientific Committee on Antarctic Research, Academic Press: London).
- HALLAS, T.E. 1975. Interstitial water and Tardigrada in a moss cushion. *Annales Zoologici Fennici* 12: 255-259.
1977. Survey of the Tardigrada of Finland. *Annales Zoologici Fennici* 14: 173-183.
- HEATWOLE, H. 1983. Community structure of organisms in Antarctic and sub-Antarctic soils. ANARE News Supplement 1: 8).
- HEATWOLE, H., SAENGER, P., SPAIN, A., KERRY, E. & DONELAN, J. 1989. Biotic and chemical characteristics of some soils from Wilkes Land Antarctica. *Antarctic Science* 1: 225-234.
- HEDWIG, J. 1801. 'Species Muscorum Frondosorum Descriptae et Tabulis Aenis LXXVII Coloratis Illustratae.' (Bärth: Leipzig).
- HOLDGATE M.W. 1967 The Antarctic ecosystems. *Philosophical Transactions of the Royal Society London, Ser. B*. 252: 363-383.
- HORNING, D.S. JR, SCHUSTER, R.O. & GRIGARICK, A.A. 1978. Tardigrada of New Zealand. *New Zealand J. Zool.* 5: 185-280.
- JENNINGS, P. 1976a. The Tardigrada of Signy Island, South Orkney Islands, with a note on the rotifers. Scotia Region. *British Antarctic Survey Bulletin* 44: 1-25.
- 1976b. Tardigrada from the Antarctic Peninsula and Scotia Region. *British Antarctic Survey Bulletin* 44: 77-95.
- LAMB, M. 1970. Antarctic terrestrial plants and their ecology. Pp. 733-751. In Holdgate, M.W. (ed.), 'Antarctic ecology' Vol II. (Scientific Committee on Antarctic Research, Academic Press: London).
- LONGTON, R.E. 1981. Interpopulation variation in morphology and physiology in the cosmopolitan moss *Bryum argenteum* Hedw. *Journal of Bryology* 11: 501-520.
- LONGTON, R.E. & MACIVER, M.A. 1974. Climatic relationships in Antarctic and northern hemisphere populations of a cosmopolitan moss, *Bryum argenteum* Hedw. Pp. 899-919. In Llano, G.A. (ed.), 'Adaptations within Antarctic ecosystems'. (Smithsonian Institution: Washington, DC).
- MARCUS, E. 1936. Tardigrada. *Das Tierreich*, Berlin-Leipzig 66: 1-340.
- MCINNES, S.J. 1994. Zoogeographic distribution of terrestrial/freshwater tardigrades from current literature. *Journal of Natural History* 28: 257-352.
- MILLER, J.D., HORNE, P., HEATWOLE, H., MILLER, W.R. & BRIDGES, L. 1988. A survey of the terrestrial micrometazoa of the Vestfold Hills, Antarctica. I. Tardigrada. *Hydrobiologica* 165: 197-208.
- MILLER, W.R., HEATWOLE, H., PIDGEON, R.W.J., & GARDNER, G.R. 1994. Tardigrades of the Australian Antarctic Territories: The Larsemann Hills, East Antarctica. *Transactions of the American Microscopical Society* 113: 142-160.
- MORGAN, C.I. & KING, P.E. 1976. 'British tardigrades'. (Academic Press: London).
- NELSON, D. & HORNING, D.S. JR 1979. Tardigrada of the Kowhai Bush, New Zealand. Pp. 125-142. In 'II International Symposium on Tardigrades. Krakow, Poland, 1977'. (Zeszyty Naukowe Uniwersytetu Jagiellońskiego: Krakow).
- OPALINSKI, K.W. 1972. Flora and fauna in freshwater bodies of the Thala Hills oasis (Enderby Land, eastern Antarctica). *Polish Archives of Hydrobiology* 19 (4): 383-398.
- RICHTERS, F. 1904. Antarktische Tardigraden. *Zoologischer Anzeiger* 31: 915-916.
- RIGGIN, G.T. 1962. Tardigrada of southwest Virginia: with the addition of a description of a new marine species from Florida. *Virginia Agriculture Experimental Station Technical Bulletin* 1962: 1-145.
- SCHUSTER, R.O. & GRIGARICK, A.A. 1970. Tardigrada of Santa Cruz Islands, California. *The Pan-Pacific Entomologist* 46: 184-193.

- SCOTT, G. & STONE, I. 1976. 'The mosses of southern Australia'. (Academic Press: London).
- SEPPELT, R.D. 1984. The Bryoflora of the Vestfold Hills and Ingrid Christen Coast, Antarctica. ANARE Research Notes 20: 1-31.
- SEPPELT, R.D. & ASHTON, D.H. 1978. Studies on the ecology of the vegetation at Mawson Station, Antarctica. Australian Journal of Ecology 3: 373-388.
- SEPPELT, R.D. & SELKIRK, P.M. 1984. Effects of submersion on morphology and the implications of induced environmental modifications on the taxonomic interpretation of selected Antarctic moss species. Journal Hattori Botanical Laboratory 55: 273-279.
- SUDZUKI, M. 1964. On the microfauna of the Antarctic region. I. Moss-Water Community at Langhovde. Japan Antarctic Research Expedition Scientific Report Series E, Publication 19. Department of Polar Research, National Science Museum. Tokyo: 1-41.
- TATUNO, S. 1963. Zytologische Untersuchungen Über die Laubmoose von Antarktis. Hikobia 3(4): 268-274.
- ZAR, J.H. 1984. 'Biological analysis'. (Prentice-Hall: New York).

## INVERTEBRATE INTERESTS IN THE WORLD CONSERVATION UNION'S SPECIES SURVIVAL COMMISSION

T.R. NEW

New, T.R. 1994 06 30: Invertebrate interests in the World Conservation Union's Species Survival Commission. *Memoirs of the Queensland Museum* 36 (1): 147-151. Brisbane. ISSN 0079-8835.

Several invertebrate groups (Lepidoptera, Odonata, social insects, orthopteroid insects, water beetles, molluscs) have become the focus of Specialist Groups in the IUCN's Species Survival Commission network. The strong insect bias reflects historical zeal and the need for other such taxon-focused attention is being addressed at present; some candidate taxa for future specialist groups are noted. The role of specialist groups is to assess the conservation needs of 'their' taxa and produce and implement an Action Plan, formulating and implementing the priority steps for conservation. An Invertebrate Conservation Task Force has been formed recently to address relevant priorities and needs. □ *Invertebrate conservation, Red Data Books, molluscs, insects, action plans.*

T.R. New, Department of Zoology, La Trobe University, Bundoora, Victoria 3083, Australia; 30 July 1993.

The International Union for the Conservation of Nature and Natural Resources (IUCN), now known as the World Conservation Union, was founded in 1948 and has immense influence as the global leader in conservation matters. It is a membership organisation which includes about 60 governments, more than 100 government departments and about 500 non-government organisations, collectively representing 120 countries.

However, invertebrate conservation is a relatively recent component of its activities, for which the initial impetus was the formation of a 'Lepidoptera Specialist Group' in the late 1970s. This was followed closely by the Invertebrate Red Data Book project, leading to publication of Red Data Books for Invertebrates (Wells et al., 1983) and Swallowtail Butterflies (Collins & Morris, 1985). A number of regional Red Data Books for invertebrates have followed more recently, particularly from Europe. The mid-eighties was marked also by the formation of several other invertebrate specialist groups, and an 'Invertebrate Issue' of the IUCN Bulletin (Collins, 1987). That early activity was attributable largely to availability of funding, and presence of two (at one time, three) permanent staff members (with assistance) at the then Conservation Monitoring Centre. Their work emphasised the formation of a preliminary database on threatened invertebrates, leading directly to the compilation of the two Red Data Books noted above. This period is discussed by Wells (1989), who emphasised that decline in invertebrate work was necessitated by reduction in core funding,

and the reorganisation of the Conservation Monitoring Centre as the World Conservation Monitoring Centre, administered jointly by IUCN, WWF and UNEP.

The largest of the six commissions of IUCN, the Species Survival Commission (SSC) is playing an increasing role in promoting invertebrate conservation, through the activities of a number of its Specialist Groups, with considerable impetus coming from a meeting in London in 1989 at which (for the first time) representatives of the various invertebrate specialist groups and other enthusiasts discussed some of the major issues and constraints. Perhaps the most important outcome was the decision to form an 'Invertebrate Conservation Task Force' to help coordinate IUCN/SSC interests, determine future priorities and devise 'Strategies' for promoting and implementing invertebrate conservation. This has proved more difficult than anticipated: the SSC network is composed largely of volunteers, and most members of the relevant Specialist Groups (below) can devote only a small (and usually unpredictable) portion of their time to such activities. Participation by chairs of the current groups, or their nominees, and by other devotees was clearly needed, with a chair who had adequate time and support. The need for global representation ensured that the Task Force members would be widely dispersed, with few chances of personal encounters, and potential chairs were among the most heavily committed people, simply because most of the people suggested for this role were known *because* of their relevant activities!

This account sets out some of the present attention to invertebrates within the activities of the SSC, and suggests how this might be increased.

#### RECOMMENDATION 41

The role of invertebrate conservation in IUCN activities was acknowledged formally by the adoption of the statement known as 'Recommendation 18/41'.

At the 18th General Assembly of IUCN, Perth, WA, 28 Nov-5 Dec 1990, this resolution on 'Conservation of Insects and other Invertebrates' was adopted by consensus. The background to the resolution, and its text, are given by Collins (1991). The resolution was proposed by the Royal Entomological Society and the Fauna and Flora Preservation Society, and was prepared by wide consultation: with the Joint Committee for the Conservation of British Insects, the Invertebrate Working Group of the National Zoo Federation, the SSC invertebrate specialist groups, the *Societas Europaea Lepidopterologica*, and the (French) Office pour l'Information Eco-entomologique. As Collins (1991) noted, this document has helped to put beliefs on the conservation of insects firmly into an international perspective.

Among other things, the Resolution urged for assistance in identifying and executing priority activities to conserve invertebrates, and support for SSC activities on invertebrate conservation.

#### THE SSC INVERTEBRATE GROUPS

The mission of the SSC ('to preserve biological diversity by developing and executing programmes to save, restore and wisely manage species and their habitats') is pursued through the medium of 'Specialist Groups', most of them taxon-focussed. This approach represents the philosophy that 'species' are meaningful units in communicating conservation concern, whereas other levels of 'biodiversity' are less tangible to many people. Other groups are 'discipline-based' (for example Captive Breeding, Reintroductions, Sustainable Use of Wild Species) and a few have been community or habitat based (Coral reef fish). Each group is fostered through a chair, appointed for a three year period and, whereas there is traditional continuity and long term membership of many groups, change is also frequent. The four goals of the SSC are:

1. To assess the conservation priorities for species and their habitats.
2. To develop plans for their conservation.
3. To initiate actions needed for the survival of species.
4. To provide an expert resource network on the conservation of biodiversity.

The aims of any of the taxon-based groups, which range in scope from single species (some mammals) through families to orders or total regional representation are (1) to determine the conservation needs for 'their' group and to set priorities, within these, (2) to produce Action Plans setting out the major needs for conservation in practice, and (3) to implement those needs, which therefore need to be clarified in some detail, including budgeting, and be practical. Recommendations for action typically range from the need for status evaluation through field survey, for habitat protection, captive breeding programmes, to aspects of legal protection or prohibition of capture. In addition, possibilities for capitalising on, or gaining mutual benefit from priorities of other groups can be relevant: many important centres for dragonflies coincide with those of birds, for example. Formulation of priorities (based both on individual taxa and important assemblages) and design of an Action Plan involves considerable coordination and, sometimes, original research to accord credibility. Action Plans, which have no legal status, are disseminated widely and provide definitive foci for conservation measures.

The number of members of a specialist group varies according to the needs perceived, and the availability of suitable people. Collectively, the 95 groups in the SSC network have about 4800 members (at March 1993).

The six present invertebrate specialist groups are:

Mollusca (18 members)

Lepidoptera (15 members: this group at one time encompassed only butterflies, as the 'Butterfly specialist group')

Social insects (18 members: at one time 'Ant specialist group')

Odonata (15 members)

Orthopteroid insects (15 members)

Water Beetles (31 members)

The Captive Breeding Specialist Group has a discrete 'subgroup' (12 members) for invertebrates.

Geographical coverage by specialist groups is inevitably uneven at present. Much impetus for invertebrate taxon-focussed conservation has come traditionally from Britain and Europe, or from North America. Group memberships reflect



this, with about 70% of collective members based in these areas. The 51% European membership base in the six main invertebrate groups is influenced heavily by the 'water beetles group', whose historical base (21/31 European members) has consolidated in that area. All six groups have members in those areas, and involvement from elsewhere is much more sporadic. Membership from the southern continents, for example, is 5 (Africa), 6 (South America) and 8 (Australasia). Also, it could be suggested that the geographical bias in memberships does not represent adequately many areas where conservation needs are greatest and most difficult to achieve and pursue. Species-focussing for conservation is, inevitably, more difficult in areas of high biological diversity and low human wealth, and where there are few resident specialists in many groups of animals and plants. There is undoubted merit in recruiting interest from those parts of the world and not imposing a eurocentric suite of conservation values likely to alienate more local interests. One theme of the Swallowtail Action Plan (below), for example, was to explore possibilities of promoting ranching of rare taxa as a sustainable cottage industry, as has been pioneered in Papua New Guinea.

#### ACHIEVEMENTS OF THE GROUPS

Individually, members of all the above groups are among the leading advocates for invertebrate conservation. Some groups have been founded only recently, and the work of the 'Orthopteroid insects' group, for example is only starting to be defined; the 'water beetle' group draws directly on the expertise of the Balfour-Browne Club in Britain, already well-organised as a group concerned about the fate of aquatic Coleoptera and their habitats. The Mollusc group has issued several numbers of a mollusc conservation newsletter ('*Tentacle*'), and the Odonata group produces 'Reports of the Odonata Specialist Group', at the rate of one or two a year.

Only one Action Plan for invertebrates has been published so far. This, for the Swallowtail Butterflies (New & Collins, 1991), drew directly from the comprehensive account by Collins & Morris (1985) and set out a representative series of 34 projects which collectively appraised the needs and practicalities for conserving the 78 species or subspecies (of 573 members of the Papilionidae) perceived as 'Threatened' in the earlier volume. Parts of this plan are the subject of active advocacy for implementation at present.

The Lepidoptera specialist group has also produced a Directory of Lepidoptera Conservation Projects (New, 1990) which it is hoped to augment and update at intervals and a volume on *Conservation Biology of Lycaenidae* (New, 1993), setting out a partial perspective for the largest family of butterflies.

Action plans for Mollusca and Odonata are well-advanced, and both groups have defined the urgent needs for their taxa. Other groups are moving towards assessing the scope and feasibility of Action Plans. The proceedings of a Mollusc Specialist Group meeting, which includes a framework for mollusc conservation action, are in press, and a recent report on European Mollusc Conservation needs (Wells & Chatfield, 1992) also emanated from the Specialist Group.

The success of any specialist group depends greatly on the zeal and enthusiasm of its members, and their ability to cover the conservation needs of the taxa.

#### NEED FOR ADDITIONAL SPECIALIST GROUPS

Clearly, the existing specialist groups are by no means fully representative of the vast panorama of invertebrate animals, or of their geographical distributions. There is a strong bias toward the insects, and several 'levels of coverage' are present - from a suite of orders, through single orders, to habitat-based 'subsets', or cross-groupings based on a particular way of life. Each contributes in different, complementary ways to a broader picture of the needs of particular invertebrate taxa.

Formation of other groups is likely to occur within the next few years, to broaden the coverage, and a number of candidate groups have been suggested. Most of these concentrate on 'flagship groups', or groups of perceived value as indicator taxa. The range of possibilities is enormous, and it is important that the most suitable invertebrate groups should be promoted through the limited logistic resources available rather than form groups with little 'realistic' conservation management potential.

It is important that

- i) The range of taxa covered is increased.
- ii) The most accessible 'key' taxa of the world's major ecosystems are addressed, and the range of habitats increased; the taxa should be ecologically informative.
- iii) A clear role for each new group is seen, rather than simply forming a group with no clear

purpose, perhaps because of strong individual advocacy.

- iv) Where possible, complementarity between the activities of different groups is sought. The groups should not overlap in interest unduly – for example by any ‘competition’ between taxon-focussed and discipline-focussed groups, unless effective (even, formal) communication occurs between the parties involved.
- v) A sufficient number of concerned and knowledgeable volunteers to form an effective group is available and the major geographical areas where the taxon occurs should have representation on the group. Where possible professional and non-professional members should be encouraged.
- vi) Where possible, the taxa should already be a main interest of societies, such as entomological groups, mollusc enthusiasts, crustacean specialists (etc), so that there may be established avenues for communication to a broad knowledgeable audience, and for seeking advice, or opportunity for group meetings at conferences or seminars, and
- vii) That logistic support be available to sustain group’s activities.

### THE TASK FORCE

One role of the Task Force, which is still in the process of defining the scope of its activities, is to recommend optimal taxa around which to attempt to form additional specialist groups, and to evaluate suggestions and proposals received for these. It will play a part in identifying important gaps in SSC invertebrate coverage, and advise on policy and programme development with respect to invertebrates. The broader aspects of its brief involve identifying avenues for promoting invertebrate conservation, identifying priorities in their conservation needs and seeking ways for these to be addressed constructively. These issues are to be combined with surveys and summaries of existing information, examination of the methodologies and approaches needed, and promoting the role of invertebrates in conservation assessment, the roles of *ex situ* conservation, formulating protocols for reintroduction and genetic maintenance, and education to improve the public image and appreciation of invertebrates. In summary, these activities collectively involve increasing the amount of logistic support for invertebrate conservation, and endeavouring to apply this in the most effective ways.

### THE ‘RED LIST’

The IUCN Red List of Threatened Animals (1988, updated 1990) lists and categorises the status of globally threatened taxa, and is assembled from the databases of the World Conservation Monitoring Centre, with input from many knowledgeable workers, including the SSC network. Well over 2000 invertebrates (representing 9 phyla) are included, many listed by species but some genera or whole families (e.g. black corals, Antipathidae) are also noted where they are perceived to be under threat. Although valuable as an initial summary, listing of invertebrates in this way poses problems (for example, through lack of knowledge of precise status, or difficulty of species-level recognition), and there is a strong bias towards the faunas of temperate regions, where species-level ‘protective legislation’ and status evaluation is most zealous. For some tropical regions, there is a greater element of subjectivity in inclusions, because precise knowledge is lacking-often reflecting the lack of local-based expertise. The invertebrate Specialist Groups are involved in attempting to update the List to the greatest level of reliability possible, within their limited resources.

Nevertheless, the diversity of taxa listed - even without precise details of status - provides pointers for future need, and one role of the Task Force will be to evaluate these progressively and to refine the invertebrate component of this important document. Current attempts to redefine the IUCN categories of threat (Mace & Lande, 1991; Mace et al., 1993) will be of major importance in this work, and allocation of invertebrates accurately to one or other of these is often difficult. Indeed, it is by no means clear whether criteria for invertebrate threat categories should be the same as for vertebrates, and it may be necessary to develop a separate suite of quantifiable values for them.

### CONCLUSION

The science of invertebrate conservation is developing rapidly, and the importance of invertebrates is becoming recognised more widely (and at more levels) than ever before. The formidable diversity of taxa involved, and the ecological ubiquity of many of the groups renders the task of their effective conservation daunting. Capability is limited at present, and there is a massive chasm between ideals and feasibility. The increasing profile of invertebrates fostered

by the IUCN, especially work on the various 'flagship' groups targeted by SSC specialist groups, is likely to be instrumental in increasing global appreciation of invertebrate biology and conservation needs, helping to placing some on a far higher level of practical attention than has been possible hitherto.

#### ACKNOWLEDGEMENTS

My participation in 'Towards Biodiversity and Conservation' was made possible by financial support from the Ian Potter Foundation and La Trobe University. I also thank Drs S.N. Stuart and A.L. Yen for comments on a draft of this paper.

#### LITERATURE CITED

- COLLINS, N.M. (ed.) 1987. Conserving Invertebrates. IUCN Special Report. IUCN Bulletin 18 (7.9): 1-20.
1991. Insect Conservation - priorities for the future. *Antenna* 15: 73-78.
- COLLINS, N.M. & MORRIS, M.G. 1985. 'Threatened Swallowtail Butterflies of the World'. (IUCN: Gland and Cambridge).
- MACE, G., COLLAR, N., COOKE, J., GASTON, K., GINSBERG, J., LEADER WILLIAMS, N., MAUNDER, M. & MILNER-GULLAND, E.J. 1993. The development of new criteria for listing species on the IUCN Red List. *Species* 19: 16-22.
- MACE, G.M. & LANDE, R. 1991. Assessing extinction threats: towards a re-evaluation of IUCN Threatened Species Categories. *Conservation Biology* 5: 148-157.
- NEW, T.R. 1990. 'Directory of Lepidoptera Conservation Projects' (La Trobe University, Department of Zoology: Melbourne).
- 1993 (ed.). *Conservation Biology of Lycaenidae (Lepidoptera)*. (Species Survival Commission: Gland).
- NEW, T.R. & COLLINS, N.M. 1991. 'Swallowtail Butterflies. An action plan for their conservation'. (IUCN: Gland).
- WELLS, S.M. 1989. SSC Invertebrate Specialist Group work - problems and potential solutions (unpublished discussion paper prepared for meeting of SSC Invertebrate Specialist Group chairmen and other invertebrate experts, September 1989, London).
- WELLS, S.M. & CHATFIELD, J.E. 1992. 'Threatened non-marine molluscs of Europe', *Nature and Environment* No 64 (Council of Europe Press: Strasbourg).
- WELLS, S.M., PYLE, R.M. & COLLINS, N.M. 1983. 'The IUCN Invertebrate Red Data Book'. (IUCN: Gland & Cambridge).

## CONSERVATION ASSESSMENT OF INVERTEBRATE ASSEMBLAGES: IS THERE A PLACE FOR GLOBAL LEVEL TAXON-FOCUSING?

T.R. NEW

New, T.R. 1994 06 30: Conservation assessment of invertebrate assemblages: is there a place for global level taxon-focusing? *Memoirs of the Queensland Museum* 36 (1): 153-157. Brisbane, ISSN 0079-8835.

The massive diversity of invertebrates, lack of taxonomic and ecological knowledge of most groups, and the low likelihood of greatly increased logistic capability to acquire this, ensure that conventional 'inventory' approaches to assessing magnitude and patterns of species diversity in natural assemblages will remain unfulfilled. In order to incorporate invertebrates meaningfully into a broad range of conservation assessment and management, some form of 'triage' seems inevitable. Possible grounds for concentrating on a restricted 'umbrella suite' of ecologically-important taxa are discussed. □ *Inventories, conservation priorities, keystone taxa, indicator taxa, umbrella taxa, flagship taxa.*

T.R. New, Department of Zoology, La Trobe University, Bundoora, Victoria 3083, Australia; 30 July 1993.

Many biologists now accept readily that impending major loss of biodiversity, equated most commonly to loss of species, is the predominant crisis facing our natural world in the next few decades and that this must be countered with the best means at our disposal. The vast, and largely unheralded, proportion of this loss will comprise invertebrate animals, whose central roles and values in contributing to sustainability of natural ecosystems are only now becoming appreciated, and for which our knowledge of diversity and distribution is minimal. Documentation and quantification of invertebrate assemblages may be regarded as a central theme in understanding 'biodiversity', and some people have argued that such knowledge is a *prerequisite* for effective conservation. However, the ideals espoused by such a stance - of collecting and describing *all* taxa of invertebrates in marine, terrestrial or freshwater assemblages as a basis for determining patterns of distribution and abundance are utopian for invertebrates as a whole and for most taxonomic groups, not least because of the decline of the taxonomic workforce and of support for 'basic' ecological surveys at all levels. It is indeed anachronistic that, at a time when the practical need for documenting faunas adequately, as basic information used in setting priorities for, and implementing, conservation management is being espoused globally as a basis for assuring global sustainability, our capability to do this is being eroded.

The urgent needs for documenting invertebrate assemblages adequately are (1) to understand the template against which we can appraise effects of anthropogenic change, (2) to increase apprecia-

tion of the ecological importance of invertebrates, and logistic support for their conservation, and (3) to apply that support in the best way(s) possible to increase management capability based on sound science and ethics. But the constraints noted above are likely to increase, and there is little realistic prospect of (for example) doubling or tripling the taxonomic workforce, or of diverting a significant proportion of the 'conservation dollar' from vertebrate issues to the assessment of largely undocumented and non-charismatic taxa or communities. We must, of course, continue to emphasise the need for increased scientific and logistic capability (and urge massively greater funding for taxonomic work), and of the underpinning role of taxonomy and collection management and interpretation as a vital tool for conservation assessment - but, also, must not let this need prevent us from making progress.

It thus seems inevitable that our rationale in seeking to document invertebrate assemblages must change, and must be adapted to accept substantial constraints and to advance our scientific capability as effectively as possible. The invertebrate conservation community must become more positive, and (whilst we must continue to bemoan lack of optimal capability) seek to make rapid progress in selected areas rather than continuing to foster the dilute approach necessitated by trying to document complex assemblages fully, or reasonably fully. One way to achieve this may be to focus our efforts more finely, and to select the most 'rational' (that is, most informative) targets by some form of 'triage', however ethically difficult this might be. Indeed, in most invertebrate surveys some degree of triage is al-

ready employed: we usually select only particular taxonomic groups for analysis, depending on criteria such as our own interest in given groups, ideas about which might give us the 'best' information or, simply, the capabilities of our assistants or whether we have expertise or access to expertise in systematic appraisal of the specimens collected. Such factors in practice already drive and restrict ecological interpretation, and our ability to analyse diverse natural assemblages in terms of the taxa present and for comparative ranking for conservation priority or importance.

However, there are often substantial difficulties in trying to compare surveys based on different taxa or habitats. There is a major need to transform what is at present little more than a series of ad hoc interpretations each depending to some extent on opportunism or local capability and giving prominence to different taxonomic groups, into an effectively assembled and coordinated data accumulation which can eventually give us great capability for comparative assessment of invertebrate assemblages, and which can help us overcome the various 'taxonomic impediments' and 'ecological impediments' which have tended to foster an air of defeatism in recent years.

### TAXON-FOCUSING

Perhaps the most effective avenue to progress would be to focus the bulk of our restricted logistic capability on a restricted suite of major taxa, and to deliberately give lower priority to most invertebrate groups. One approach to this (New, 1993) could be to delimit a large 'umbrella suite' of phyla for attention, from which smaller segregates may be selected progressively in a range of different habitats and ecological contexts. New (1993) suggested that perhaps no more than 9 phyla need consideration in order to gain a sound comparative database on distribution, diversity, and ecology relevant to conservation of all (or most) other invertebrate groups. Briefly, the criteria used to delimit such a suite (Appendix 1) seek to capitalise as effectively as possible on the knowledge and capability available. They emphasise (1) the relative knowledge which exists at present and (2) the groups' capability to augment ecological understanding, so that the major 'values' adduced are scientific ones. The groups are those whose incidence and abundance can be used most effectively to assess the wellbeing of communities and ecosystems. The phyla suggested as particularly useful for this exercise

are Cnidaria, Porifera, Platyhelminthes (Turbellaria), Mollusca, Annelida, Onychophora, Arthropoda (s.l.), Bryozoa, and Echinodermata. The principle of deliberately de-emphasising most invertebrate phyla or, at least, omitting them from quantitative assessment for conservation is certainly a difficult one to espouse and this 'umbrella suite' is a suggested one only, to demonstrate the principle involved. It includes virtually all invertebrate groups which have been the subject of species-orientated conservation studies or used as indicator taxa; at that level, therefore, this grouping does little more than formalise the status quo. I also emphasise that omission of any group from this suite of preferred taxa does not demean its importance or relevance, or suggest that it is any way 'expendable'. It is not, but many of the poorer known invertebrate groups are likely to be conserved more effectively by being placed under an ecologically comprehensive umbrella than by being appraised individually when this entails a massive 'catch up' operation or is logistically intensive to achieve. By concentrating our efforts on a suite of taxa likely to yield 'high knowledge dividends', many (most) other groups may gain benefit.

The implicit priority is to augment capability for a number of ecologically informative invertebrate groups which are already relatively well known, which have definable ecological values and for which a core of capability is available. We are clearly committed to levels of extrapolation or of generality in seeking to define assemblages quantitatively but need to seek both 'diversity in generality' and 'generality in diversity', emphasising that although we desire to know all the animals present there is no *practical* likelihood that we shall ever do so at any ecologically meaningful level. In essence, invertebrate conservation zoologists have to learn to redress the feelings of academic defeat of not being able to assess total assemblages completely, to move on from arguing about numbers of species per se and to develop a practical framework to safeguard organismal biodiversity on pragmatic grounds. Focussing on particular groups is more likely to enable assembly of a broadly applicable data set within a foreseeable period, than continuing to pursue broader, more academically satisfying but less attainable, goals.

Other, alternative or complementary, approaches are of course possible. Rather than primary delimitation at the phylum level, lower level taxa (orders, families) from a wider range

of phyla could be selected for intensive appraisal. This could indeed incorporate particularly relevant other groups of a wider spectrum of invertebrates whilst not diverting from the main thrust of focusing logistic capability. Either of these approaches (or a combination of them) thus differs markedly from approaches such as 'guild analysis' of assemblages, whereby it may still be necessary to systematically interpret all invertebrate groups and enhance the taxonomic capability to do so.

A carefully-selected 'umbrella suite' of taxa is likely to obviate the need for this.

It could be suggested, as has occurred in some past studies, that all invertebrates may be safely conserved in natural communities by the more 'usual umbrellas' of vertebrates and vascular plants, and that a logical extension may be to ignore them completely in assessment of assemblages. However, there is abundant evidence that the ecological sensitivities of invertebrates in all major ecosystems may be extraordinarily subtle and that their partitioning of resources may be undertaken in very intricate and sensitive ways. Unless they are indeed incorporated in assessment of the 'health' of natural assemblages, much subtlety may be lost simply through ignoring the detailed needs of the predominant components of those assemblages and losing capability to monitor the effects of anthropogenic intrusion. Simply, invertebrate assemblages cannot be assessed properly without assessing invertebrates themselves in any context where broad comparisons may be needed.

Any particular ecological survey may necessitate acquisition of a massive amount of data specific to that study. Its value could be enhanced dramatically if the main data were immediately relevant to, and available for, incorporating into broader national or global comparative scenarios. Di Castri et al. (1992) emphasised the importance of rapid standardised methods for survey for ranking or assessing communities, and this theme pervades other recent discussion (see Spellerberg, 1993, for examples). Di Castri and his colleagues noted that all major trophic groups should be included in the representative taxa used for assessment; that all main size groups, species-rich and species-poor groups, and groups containing common and rare species should be incorporated; and that, for example, '10-15 families of insects' should be included.

Important steps that might now be taken to recognise the need to increase our capability to study natural assemblages include:

- i) to discuss the values of 'taxon triage' over any more comprehensive approach;
- ii) to gain a broad consensus on the groups of invertebrates we need to assess, or which merit priority, in assessing assemblages in different habitats;
- iii) to derive protocols for sampling and assessing those taxa in standard comparable ways (ranging from devising optimal sampling sets to production of identification manuals and sets of voucher material for distribution to users), enabling their use for various forms of ordination analysis, and the sound recognition and delimitation of 'notable' species;
- iv) to increase global capability for interpreting the distribution of the priority groups and evaluating their responses to habitat change or other disturbance, and
- v) to incorporate information on them into what will eventually become more comprehensive databases useable for both specific and comparative assessment.

## DISCUSSION

Optimal taxonomic groups (be they at phylum or low levels of selectivity) in any such scheme of taxon-focusing to enhance invertebrate conservation should be selected in relation to the kinds of ecosystem being assessed and the properties of the species involved. These are inter-related: initial appraisal of major ecosystem categories and comparison between these in different continents and climatic regimes (as suggested by di Castri et al., 1992) is likely to reveal the various suites of invertebrate taxa which will complement each other in general themes of gathering information and increasingly sophisticated use of indicator taxa as well as the delineation of critical faunas based on criteria such as high diversity, high endemism or the presence of notable or rare species. The basis for some such survey for many groups is already available in literature.

This approach is not meant to deter species-orientated conservation for threatened taxa of any invertebrate group; this is a different exercise from taxon-focusing for defining and setting priorities in assemblages and, clearly, any especially notable species has the potential to become an 'umbrella' or 'flagship' in its own right. Generally, the phylum level is too embracing for this—except, possibly, in the case of relatively small and notable groups such as the Onychophora (New, 1994). Onychophora are a group for which the general appearance is unam-



biguous. Their detailed systematics are complex but the mere presence of any species may be sufficient to mark out a forest or grassland site, or a cave, as being of conservation significance. They are potentially useful flagships (and umbrellas) for the multitude of less conspicuous invertebrates, mostly known even less well, which also occur in wet forest habitats, for example. By contrast, many arthropod groups manifest strongly all or most of the features on which other phyla in their entirety have been excluded from the 'umbrella suite': small size, general inaccessibility or difficulty of comprehensive sampling, lack of taxonomic knowledge and agreement, intangible diversity, little ecological knowledge or distributional information, or an entirely parasitic mode of life. These factors can guide us constructively in our selection of focal orders or families within most of the larger phyla. It may be profitable to select some 'taxon sets' on a regional basis, rather than globally, but there should be provision for the greatest amount of comparative assessment possible. For example, incorporation of groups such as tardigrades and rotifers for assessing low diversity Antarctic terrestrial communities (Usher & Edwards, 1986) is rewarding, but these groups may have less relevance elsewhere.

The twin roles of invertebrates in conservation assessment may be summarised as (1) diversity or presence/absence of particular taxa reflecting the complexity or 'health' of natural communities, and (2) monitoring the changes wrought by changed conditions, perhaps more effectively than can be achieved by using other organisms. 'Biological indicators' is a very broad term, but there has been considerable recent interest in selecting groups of invertebrates whose presence or abundance can indeed indicate environmental health sensitively. For examples, Spellerberg (1993) delimited five categories of pollution indicators alone, and a recent volume on benthic invertebrates (Resh & Rosenberg, 1993) demonstrates their wide indicator relevance in freshwater communities.

Any relatively well-known invertebrate group which can embrace values of traditional indicator, flagship or umbrella properties probably merits high priority. If it proves possible to delimit keystone groups (reef-building corals are one example), this criterion would be especially important; however, the more general perception of 'keystones' at present tends to be at the species level, rather than the higher taxon. But I believe that it is indeed possible to incorporate such a

range of ecological considerations into taxon delimitation, and that the habitat formation is the background against which optimal groups must be decided.

At present the future for invertebrate conservation is in the balance, and prospects for the emerging science are critical. On the one hand we can continue as we are, largely uncoordinated and having heated discussions about levels of diversity and the values of particular species, and—perhaps—seeing our restricted resources diluted to suboptimal ends through lack of focus. On the other hand, we can seek a different or more coordinated focus, involving a level of triage at either the taxon level or the community (or major habitat) level. My comments today are directed to the first of these changes, with the implication that complementarity between the preferred groups will indeed give us a sound understanding of broader aspects of invertebrate assemblages and guide us effectively toward their management.

#### ACKNOWLEDGEMENTS

My participation in 'Towards Biodiversity and Conservation' was facilitated by financial support from the Ian Potter Foundation and La Trobe University. I appreciate comments on a draft of this paper from Dr A.L. Yen, and several other colleagues raised points at the meeting which have helped to clarify particular aspects.

#### LITERATURE CITED

- DICASTRI, F., VERNHES, J.R. & YOUNES, T. (eds) 1992. Inventorying and monitoring biodiversity. A proposal for an international network. *Biology International. Special Issue No 27*: 1-28.
- NEW, T.R. 1993. Angels on a pin: dimensions of the crisis in invertebrate conservation. *American Zoologist* 33:623-630.
1994. Onychophora in invertebrate conservation: priorities, practice and prospects. *Zoological Journal of the Linnean Society* (in press).
- RESH, V.H. & ROSENBERG, D.M. (eds) 1993. 'Freshwater biomonitoring and benthic macroinvertebrates'. (Chapman & Hall: New York).
- SPELLERBERG, I.F. 1993. 'Monitoring ecological change'. (Cambridge University Press: Cambridge).
- USHER, M.B. & EDWARDS, M. 1986. The selection of conservation areas in Antarctica: an example using the arthropod fauna of antarctic islands. *Environmental Conservation* 13: 115-122.



## APPENDIX

Criteria for designating a suite of invertebrate phyla for priority study to construct data bases for conservation assessment and to act as a broad umbrella suite for conservation of other invertebrates (after New 1993).

- 1) Include marine, freshwater and terrestrial taxa, and groups crossing these systems in various combinations; all major ecosystems represented repeatedly.
- 2) All feeding modes and trophic levels replicated, and diverse ways of life represented; emphasis on 'free-living' taxa; all significant ecological roles and interactions, with indicator groups to monitor these, incorporated.
- 3) Most geographically widespread, but also include local endemics, critical faunas, or 'hot-spots' of diversity in selected range of areas.
- 4) Most diverse, but with established taxonomic frameworks for all, or significant, sections.
- 5) Substantial existing ecological information, such as
  - i) taxa promoted/used as indicators
  - ii) possibility of expanding from documented existing foci (such as case-studies)
- 6) 'Values' defined or definable, including range of 'commodity' or 'applied' aspects likely to engender political support.
- 7) Possibility of incorporating taxa in educational programmes, for example to help overcome prejudice against invertebrates.
- 8) Amenable to capture/sampling by standard or simple techniques which can be replicated easily and combined into sampling sets. Possibilities for laboratory rearing to facilitate *ex situ* conservation.
- 9) 'Critical mass' of workers on group exists, with realistic potential for global/ international cooperation and complementarity.
- 10) Knowledge base founded in museum and other institutional collections can be used to document the critical nature and define distributions for selected taxa.

## BIODIVERSITY OF TROPICAL POLYCLAD FLATWORMS FROM THE GREAT BARRIER REEF, AUSTRALIA

L.J. NEWMAN AND L.R.G. CANNON

Newman, L.J. & Cannon, L.R.G. 1994 06 30: Biodiversity of tropical polyclad flatworms from the Great Barrier Reef, Australia. *Memoirs of the Queensland Museum* 36(1): 159-163. Brisbane. ISSN 0079-8835.

Prior to our work, only 16 polyclad flatworms had been recorded from the entire Great Barrier Reef. In the past, these delicate worms proved difficult to collect and virtually impossible to fix. Since 1989, we have documented 134 species of polyclads (over 90% new) from two locations in the southern Great Barrier Reef. These results indicate that the biodiversity of tropical marine polyclads is much greater than was previously thought. □ *Platyhelminthes, Polycladida, flatworm, colour pattern, biodiversity, Australia, Great Barrier Reef.*

L.J. Newman & L.R.G. Cannon, Worms Section, Queensland Museum, PO Box 3300, South Brisbane, Queensland, Australia 4101; 31 August 1993.

Marine polyclad flatworms (Platyhelminthes, Polycladida) are often regarded as conspicuous inhabitants of tropical reefs yet surprisingly little is known about either their biology or diversity. Tropical polyclads are known as pests of oysters (Stead, 1907) and giant clams (Newman, et al., 1993), associates of soft corals (Cannon, 1990), brittlestars (Cannon & Grygier, 1991), molluscs, crustaceans, echinoderms and corals (see Prudhoe, 1985). Less than 20 studies have considered Australian polyclads (e.g. Hyman, 1959; Prudhoe, 1977, 1982; Cannon, 1990; Cannon & Newman, 1993) and only 16 species are recorded from the Great Barrier Reef (GBR) (Haswell, 1907; Prudhoe, 1985; Cannon & Newman, 1993; Newman et al., 1994) — and of these species, only two have been described since 1907.

The diversity of tropical polyclads is poorly understood for a variety of reasons. Firstly, many descriptions are based on single, immature, preserved specimens or even only on water colour illustrations. Secondly, polyclads are rarely collected intact since they tend to fall apart when stressed and as a consequence they are inadequately represented in museum collections. Furthermore, seldom have their colour patterns been adequately recorded. Finally, the habitats and biology of these flatworms are poorly known.

The colourful pseudocerotid polyclads have been previously identified on the basis of their colour pattern (Hyman, 1954, 1959; Prudhoe, 1985, 1989) and confusion has arisen over the reliability of this for species descriptions. According to Prudhoe (1985) colour and markings are the only means by which pseudocerotids can be identified (although this was often poorly recorded). Conversely, Faubel (1983, 1984)

maintained that the comparative morphology of the reproductive system was an essential tool for species diagnosis for turbellarians. Serial reconstruction of the male and female reproductive structures is time consuming and has not been consistently used for species descriptions.

### POLYCLADS PRESENT

We collected polyclads by hand from under coral rubble at the reef crest and under ledges from the reef slope at Heron and One Tree Islands, southern GBR, from 1989 to 1993. All species were examined live before fixation and their colour patterns recorded photographically either in situ or in the laboratory.

Our study of tropical polyclads has been greatly enhanced by the development of a new fixation technique which ensures animals are preserved flat, intact and retain their colour patterns (Newman & Cannon, in press). Over 800 specimens (whollemounts and serial sections) with colour transparencies are lodged at the Queensland Museum. For species descriptions we have relied on examination of morphological characters of living animals, colour pattern and on reconstruction of the reproductive anatomy from longitudinal serial sections of mature animals.

To date, 134 species belonging to 6 families (Suborders Acotylea and Cotylea) of marine polyclads have been collected from the southern Great Barrier Reef (GBR). We considered 123 species (over 90%) to be new (Table 1) with two new genera and one new family.

Comparison of collecting data showed that the number of species collected per sampling trip did not diminish with time. Overall, 1.3 to 3.0 species

TABLE 1. Summary of polyclads collected from Heron and One Tree Islands.

Order & Family	Genus	# Spp. known	# Spp. 'new'
Suborder Cotylea			
Pseudocerotidae			
	<i>Pseudoceros</i>	5	45
	<i>Pseudobiceros</i>	4	8
	Nov. genus # 1	0	8
	Nov. genus # 2	0	7
	<i>Thysanozoon</i>	0	2
	<i>Acanthozoon</i>	0	1
	unidentified	0	14
Euryleptidae			
	<i>Eurylepta</i>	1	7
	<i>Cycloporus</i>	0	3
Nov. Family # 1		0	1
Suborder Acotylea			
Callioplanidae		1	2
Planocercidae		0	10
Stylochidae		0	2
	unident. acotyleans	0	7
	Total no. spp.	11	123

were collected per sampling day and the number of new species collected per sampling day ranged from 0.4 to 2.2 (Table 2). The cumulative total of new species also rose steadily with each trip and this number is predicted to continue to increase with time by the curve (Fig. 1). These results indicate that more new species can be expected be found from the southern GBR (Fig. 1). Interestingly, all of the previously known species were collected during the first sampling trip and remained virtually constant over time.

The most diverse and abundant polyclads from the southern GBR belong to the Pseudocerotidae, which are generally the most flamboyantly coloured flatworms. The Euryleptidae were the second most diverse family: these worms were also found to be flamboyantly coloured, often

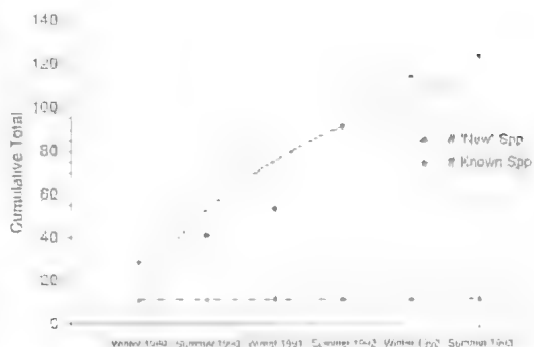


FIG. 1. Cumulative totals of known and 'new' species from Heron and One Tree Islands (1989-1993).

possessing similar colour patterns to the pseudocerotids (Fig. 2). The Planocercidae were the most abundant group of acotyleans: these polyclads were generally cryptic, avoiding sunlight and consequently were more difficult to find.

Colour documentation of living flatworms has proven critical to the study of tropical polyclads. Results showed that similar colour patterns occurred in: (1) different families, viz. Pseudocerotidae and Euryleptidae (Fig. 2 A,B); (2) in different genera, viz., *Pseudoceros* and *Pseudobiceros* (Fig. 2 C,D); and (3) two genera where the pattern is the same but the colour is reversed *Pseudoceros* and *Pseudobiceros* (Fig. 2 E,F).

Field observations showed that the most common polyclads, the pseudocerotids, were found feeding on a variety of colonial ascidians evidently showing nonspecificity in their diet. During feeding, pseudocerotids expand the folds of their highly ruffled pharynx into the individual zooids of colonial ascidians. Worms collected under boulders at the reef crest often left feeding scars when they were removed from their prey and one species was consistently collected from within the test of its prey, an ascidian. Pseudocerotids did not feed in aquaria and further study of preferences may be hampered by the difficulty in keeping ascidians healthy in aquaria. No other prey was observed being consumed although

TABLE 2. Summary of collecting data from Heron and One Tree Islands.

Collecting trip	Total # spp.	# Spp. known	# 'New' spp.	# Sampling days	Total # spp./day	# 'New' spp./day
Winter 1989	39	11	28	22	1.8	1.3
Summer 1990-91	15	0	13	6	2.5	2.2
Winter 1991	22	0	12	17	1.3	0.7
Summer 1991-92	66	0	38	23	3.0	1.7
Winter 1992	57	0	23	35	1.6	0.7
Summer 1992-93	51	0	9	23	2.2	0.4

these polyclads were also found on sponges and coralline algae. Callioplanids, however, were found on several occasions in the field with a small intact gastropods, *Turbo perspicuosus* (Iredale, 1929), in their pharynx or digestive tract.

### POLYCLADS FUTURE

Despite their relatively large size (average of 20-50mm) and their conspicuous and flamboyant colour patterns, polyclads were poorly repre-

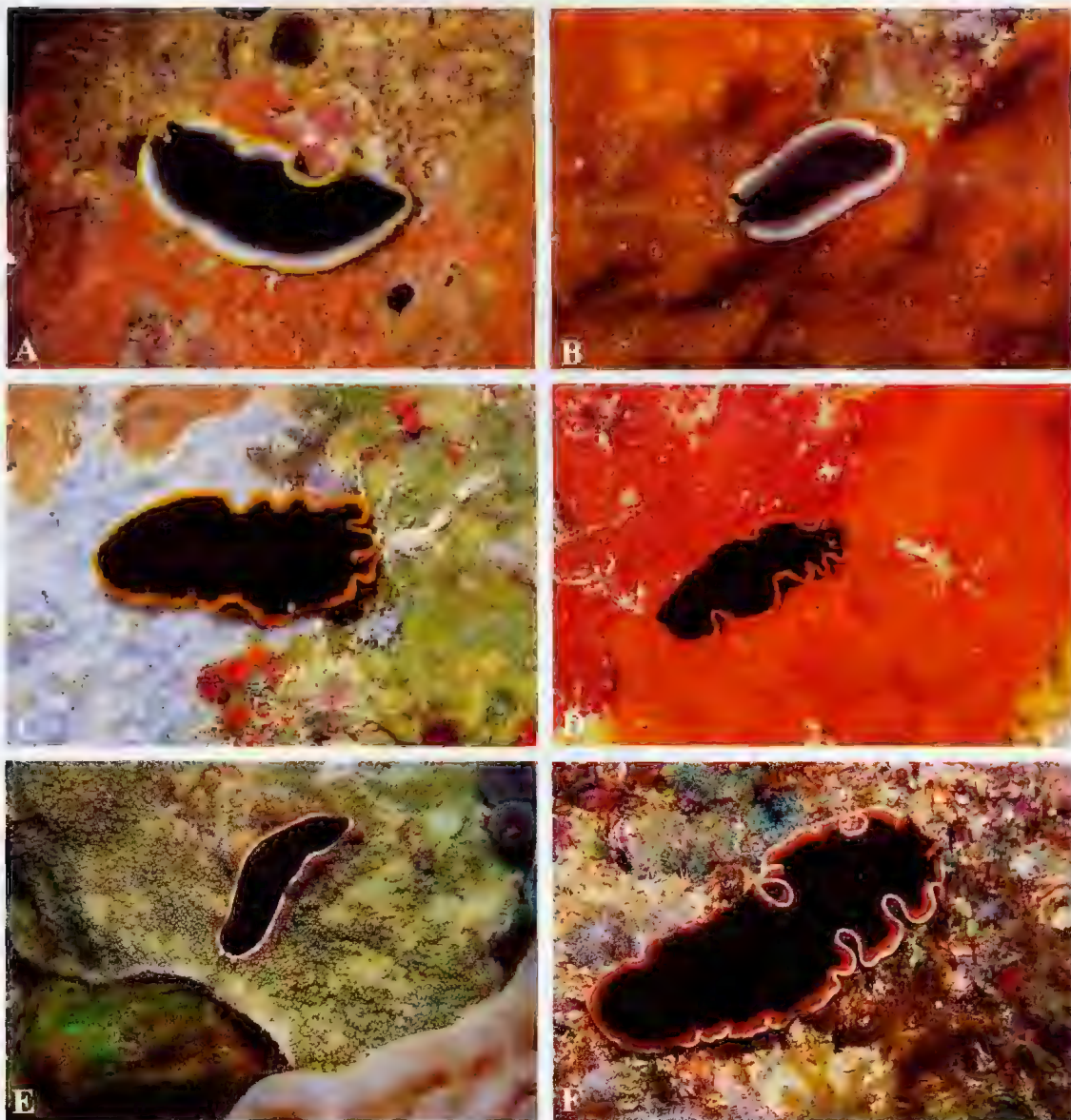


FIG. 2. Colour variation in cotyleans. Between families: A, Pseudocerotidae; B, Euryleptidae. Between genera: C, *Pseudoceros* sp.; D, *Pseudobiceros*. Colour reversal between genera: E, *Pseudoceros* sp.; F, *Pseudobiceros hancockanus* (Collingwood, 1876).

sented from tropical waters of the GBR (Prudhoe, 1985; Cannon & Newman, 1993; Newman et al., 1994). Clearly any inference that the small number of currently described species indicates low polyclad diversity in these tropical waters is wrong. Our results have shown that the flatworm fauna is extremely diverse at Heron and One Tree Islands and over 90% of the animals collected have not been described. This is the highest diversity for these worms recorded for one location in the world. Furthermore, the notion that these marine invertebrates may be rare and difficult to find has been proven false by our demonstrated success in collecting.

Examination of live animals has provided the opportunity to document new morphological characters such as pharynx shape and size, marginal tentacle shape and marginal and cerebral eye arrangement. As a consequence, these new taxonomic characters are being used to redescribe known species, describe new species and designate new genera.

The improved fixation techniques and the use of colour photography and field observations on live animals has enabled us to recognise new characters, which, together with reconstruction of the reproductive anatomy, will enable new taxa to be described.

We have shown, for example, that the same colour pattern can occur in different genera and even in different families. Colours have also been found reversed between different genera. These results show that colour pattern cannot reliably be used to differentiate genera or families. Whether colour pattern alone can be used to separate species remains unanswered without further study and comparisons made of the reproductive structures.

The biological significance of flamboyant colours in polyclads may be related to the toxicity of these worms. Several polyclads are reported to contain toxins such as tetrodotoxin (Halstead, 1978; Miyazawa et al., 1986; Flowers, pers. comm.). Further studies are needed on chemical defence in polyclads in order to determine which groups are toxic. Certainly, some pseudocerotids are known to mimic toxic opisthobranch molluscs (Brunckhorst, 1988; Gosliner & Behrens, 1990; Newman et al., 1994).

The true diversity of tropical marine polyclads is now just being recognised. Increased awareness of polyclad diversity is related to new fixation techniques, accessibility to the reef, and recognition of the importance of live study and

photography to determine habits, habitus and habitats.

## ACKNOWLEDGMENTS

Many people assisted in the delicate task of collecting polyclads; we would especially like to thank; Mr A. Flowers, Ms M. Preker, Mr H. Peterken, Ms S. Whittingham and Mrs J. Marshall. Mr A. Flowers helped immensely with collecting and photography; Ms Z. Khalil and Ms C. Lee did the histological preparations, and Mr B. Cowell helped with the colour plate. Kim Sewell and Peter Davic made useful comments on the manuscript. We are also grateful to the Heron Island Research Station Director and the Managers of the One Tree Island Research Station. Dr I. Lawn and Ms M. Preker are thanked for their support and advice. This project was generously supported by P&O Pty Ltd/Heron Island Research Station Reef Fellowship (to L.N.) and the Australian Research Council Grant # AD 90318306 (to L.R.G.C.).

## LITERATURE CITED

- BRUNCKHORST, D.J. 1988. Amazing aposematic phyllidiid nudibranchs — some interdisciplinary perspectives. P.88, In Proceedings of the Australian Marine Science Association Jubilee Conference, Sydney, December 1988.
- CANNON, L.R.G. 1990. *Apidioplana apluda* n.sp., a new polyclad turbellarian symbiote of gorgonian corals from the Great Barrier Reef, with a review of the family Apidioplanidae. *Memoirs of the Queensland Museum* 28: 435-442.
- CANNON, L.R.G. & GRYGIER, M.J. 1991. The turbellarian *Notioplana comes* n. sp. (Leptoplanidae: Acotylea: Polycladida) found with the intertidal brittle star *Ophiocoma scolopendrina* (Ophiocoma: Ophiuroidea) in Okinawa, Japan. *Galaxea* 10: 23-33.
- CANNON, L.R.G. & NEWMAN, L.J. 1993. Polycladida. Pp. 82-83, Pl. 4. In Mather, P. & Bennett, I. (eds), 'A coral reef handbook.' (Surrey Beatty and Sons: Sydney).
- FAUBEL, A. 1983. The Polycladida, Turbellaria. Proposal and establishment of a new system. Part I. The Acotylea. *Mitteilungen aus dem hamburgischen zoologischen Museum und Institut* 80: 17-121.
1984. The Polycladida, Turbellaria. Proposal and establishment of a new system. Part II. The Cotylea. *Mitteilungen aus dem hamburgischen zoologischen Museum und Institut* 81: 189-259.
- GOSLINER, T.M. & BEHRENS, D.W. 1990. Special resemblance, aposematic colouration and mimicry in opisthobranch gastropods. Pp. 127-



138. In Proceedings of a Symposium Sponsored by the American Society of Zoologists, June 1990.
- HALSTEAD, B.W. 1978. 'Poisonous and venomous marine animals of the World. Vol. 1.' (The Darwin Press: Princetown, New Jersey).
- HASWELL, W.A. 1907. Observations on Australian polyclads. Transactions of the Linnean Society, London (2) Zoology 9: 465-485.
- HYMAN, L. H. 1954. The polyclad genus *Pseudoceros*, with special reference to the Indo-Pacific region. Pacific Science 8: 219-225.
1959. Some Australian polyclads. Records of the Australian Museum 25: 1-17.
- MIYAZAWA, K., JOEN, J.K., MARUYAMA, J., NAGUCHI, T., ITO, K. & HASHIMOTO, K. 1986. Occurrence of tetrodotoxin in the flatworm *Planocera multitentaculata*. Toxicon 24: 645-650.
- NEWMAN, L.J. & CANNON, L.R.G. (in press). The importance of fixation of colour, pattern and form in tropical Pseudocerotidae (Platyhelminthes, Polycladida). Hydrobiologia.
- NEWMAN, L.J., CANNON, L.R.G. & BRUNCKHORST, D.J. 1994. A new flatworm (Platyhelminthes, Polycladida) which mimics a phyllidiid nudibranch (Mollusca, Nudibranchia). Zoological Journal of the Linnean Society 110: 19-25.
- NEWMAN, L.J., CANNON, L.R.G. & GOVAN, H. 1993. *Stylochus (Imogene) matatasi* n. sp. (Platyhelminthes, Polycladida): Pest of cultured giant clams and pearl oysters from Solomon Islands. Hydrobiologia 257: 185 - 189.
- PRUDHOE, S. 1977. Some polyclad turbellarians new to the fauna of the Australian coasts. Records of the Australian Museum 31: 586-604.
1982. Polyclad turbellarians from the southern coasts of Australia. Records of the South Australian Museum 18: 361-384.
1985. 'A monograph on polyclad Turbellaria'. (Oxford University Press: Oxford).
1989. Polyclad turbellarians recorded from African waters. Bulletin of the British Museum, Natural History (Zoology) 55: 47-96.
- STEAD, D.G. 1907. 'Preliminary note on the wafer (*Leptoplana australis*), a species of dendrocoelous turbellarian worm, destructive to oysters'. (Department of Fisheries, New South Wales: Sydney).

## ENVIRONMENTAL CONTROL OF THE LOCAL-SCALE DISTRIBUTION OF FUNNEL ANTS, *APHAENOGASTER LONGICEPS*

A.O. NICHOLLS AND N.J. MCKENZIE

Nicholls, A.O. & McKenzie, N.J. 1994 06 30: Environmental control of the local-scale distribution of funnel ants, *Aphaenogaster longiceps*. *Memoirs of the Queensland Museum* 36(1): 165-172. Brisbane. ISSN 0079-8835.

*Aphaenogaster longiceps*, the funnel ant, is widespread in southern Australia. The genus is generally regarded as being more common on, or confined to, sandy soils ranging from the inland to the coastal forests. In this paper we model the effect of site, soil and vegetation characteristics on the probability of occurrence of nests of *A. longiceps*. The relative strength of the environmental variables in predicting the presence of nests of *A. longiceps* within a 20ha site in SE New South Wales is described. Aspect and topographic position are better predictors of nest occurrence than are surface soil texture (percent gravel and percent sand) or vegetative characteristics. The models are used to predict the likely response of *A. longiceps* to forest habitat fragmentation in eucalypt forest in SE New South Wales. □ *Hymenoptera, Formicidae, funnel ant, Aphaenogaster longiceps, species distribution, statistical modelling, logistic regression, habitat fragmentation, Wog Wog, Australia.*

A.O. Nicholls, CSIRO, Division of Wildlife and Ecology, PO Box 84, Lyneham, A.C.T. 2602; N.J. McKenzie, CSIRO, Division of Soils, GPO Box 639, Canberra, A.C.T. 2601; 29 July 1993.

The impact of forest habitat fragmentation on the ground dwelling arthropod fauna of a eucalypt forest is currently being studied at Wog Wog, SE New South Wales (Margules, 1992). The primary objectives of this experiment are to test predictions that flow from MacArthur & Wilson's (1967) equilibrium theory of island biogeography. The theoretical background, experimental design, sampling stratification and theoretical predictions are described by Margules (1992). In brief, there are two predictions of importance: the first is that habitat fragmentation reduces diversity and second that the reduction in diversity is dependent upon the fragment size (Margules, 1992). The major emphasis of the experiment is on the ground dwelling arthropod fauna. Herbage and understorey layers are also being monitored (Austin & Nicholls, 1988; Margules, 1992) to document their dynamics following habitat fragmentation and for the potential influence they might have on the distribution and abundance of the sampled fauna.

Funnel ants, *Aphaenogaster* spp., are known for their habit of creating widespread surface soil disturbance in association with their nest entrances (Sloane & Sloane, 1964; Saunders, 1967; Andersen, 1991). They can be a conspicuous component of the ground dwelling fauna and can influence the dynamics of the ground layer vegetation (Saunders, 1967). The presence of the

nests of *A. longiceps* was recorded as part of the characterisation of the permanent monitoring sites in the Wog Wog experiment. The nests did not seem to be randomly distributed with respect to other site environmental variables.

The preference of *Aphaenogaster* spp. for selected habitats has been noted before (Saunders, 1967; Andersen, 1991); it is generally observed that *Aphaenogaster* spp. prefer sandy soils. Although there has been only limited work on habitat preferences of Australian ants there is clear evidence that ants can show affinities for selected soil types (Greenslade, 1976, 1987), aspects (Greenslade, 1985) and can partition the habitat in terms of rainfall gradients (Greenslade, 1974, 1976, 1987).

The objective of the present paper is to develop and describe correlative models relating the presence of nests of *A. longiceps* to a range of environmental variables that potentially represent different sources of control of the distribution of the species. These models will be used to predict the likely impact of forest fragmentation on this conspicuous component of the ground dwelling arthropod fauna.

## METHODS

In 1987 an environmental survey of the 144 permanent sampling points within the Wog Wog



TABLE 1. Variables recorded for each permanent monitoring site grouped into three broad categories. Categorical variables or factors are indicated by the number of levels within brackets. Soil colour was recorded using the Munsell Color Company (1971) hue, value, chroma notation; electrical conductivity (EC) in a 1:5 water solution. Organic carbon is abbreviated as OC.

Topographic	Edaphic	Vegetational
Slope	A horizon	% Bare ground
Aspect	% Sand	% Litter cover
Landform(9)	% Clay	(leaves, bark,
Habitat(2)	% Gravel	grass, logs)
Catchment size(4)	Colour	% Shrub cover
Fire History(3)	Thickness	( <i>Kunzea</i> , <i>Acacia</i>
Water Erosion(2)		<i>Eucalyptus</i> , other)
	B horizon	% Grass cover
	% Sand	% Herb cover
	% Clay	% Cryptogam cover
	% Gravel	(moss, lichens)
	Colour	% Cover ferns
		% Canopy cover
	EC	( <i>Eucalyptus</i> ,
	pH	<i>Acacia</i> )
	Organic Carbon	

habitat fragmentation experiment was carried out just prior to the clearing of the surrounding forest. Variables were recorded in three broad classes: topographic, edaphic and vegetational (Table 1). Each permanent monitoring site consists of two 3×3m quadrats, separated by distances that varied from two to about four metres, on which most vegetational variables were recorded. The only vegetational characteristics not measured on these quadrats were the canopy cover of *Eucalyptus* spp. and *Acacia* spp., which were estimated for a 10×10m quadrat centred on a soil auger hole placed between the two 3×3m quadrats. Edaphic data were collected from this auger hole and associated samples submitted for laboratory analysis. Topographic data were recorded from the same location as the edaphic data. Presence or absence of nests of *A. longiceps* were recorded for each 3×3m quadrat.

The relationship between the presence or absence of nests of *A. longiceps* and the different suite of environmental variables was determined by fitting a statistical model — a multivariate logistic regression, from the class of regression

models known as generalised linear models (McCullagh & Nelder, 1989). Numerous examples of the application of logistic regression models to demonstrate the relationship between the presence or absence of a species and a suite of environmental variables have been published for both plant species (Austin et al., 1983, 1984, 1990; Nicholls, 1989) and animal species (Adler & Wilson, 1985; Lindenmayer et al., 1991a, 1991b). Models were developed using the forward stepwise variable selection strategy outlined by Nicholls (1989) for predicting the probability of occurrence of *Eucalyptus radiata* as a function of a set of climatic, topographic and geological variables. The presence of a monotonic response as opposed to a unimodal response in each continuous variable was tested by fitting and comparing both first and second order polynomial functions.

A separate model was developed to estimate the probability of nest occurrence as a function of the variables belonging to each of the classes listed in Table 1. This permits an intuitive approach to evaluating the relative strength of the three models while permitting one to look at the variables that are correlated with the presence of *Aphaenogaster* nests. A more formal approach to this relative evaluation would be to use the forward selection procedure across all variables from all three classes. The usual set of regression diagnostics, techniques developed to assist with the evaluation of the assumptions implicit in fitting regression models to data, were applied to the final models to assess observations not well fitted by the model (outliers) and observations with undue or potential influence on the parameter estimation (Nicholls, 1989; Hosmer & Lemeshow, 1989; Collett, 1991).

#### MODELS FOR INDIVIDUAL CLASSES OF VARIABLES

##### TOPOGRAPHIC VARIABLES

A number of variables showed significant relationships when tested singly. Of these the following were the most important: aspect, the experimental design factor habitat (slope or drainage line), catchment size and landform (Table 2). The variables — habitat, landform and catchment size — produced a significant improvement when added to a model with aspect (Table 3). The variables slope and landform produced significant improvement in a model including aspect and habitat. Of these, slope was the most important and was added to the model.

TABLE 2. Changes in deviance (a measure of the lack of fit used to assess logistic regression models fitted to binary data) when the topographic variables were fitted singly to the null model. This table represents the results of the first pass of the forward stepwise fitting procedure.

Variable	d.f.	Deviance	d.f.	Deviance	P
Null	287	213.09			
Slope	286	212.68	1	0.412	>0.1
Slope+Slope <sup>2</sup>	285	211.59	1	1.097	>0.1
Aspect	286	181.80	1	31.294	<0.001
Aspect+Aspect <sup>2</sup>	285	178.45	1	3.353	0.067
Landform	279	180.51	8	32.582	0.001
Habitat	286	194.55	1	18.544	<0.001
Catchment size	284	193.19	3	19.904	<0.001
Fire History	285	210.02	2	3.081	>0.1
Water Erosion	286	208.27	1	4.822	0.028

Subsequent testing of the remaining variables produced no further significant reduction in the deviance. Thus a three variable model proved to be an adequate model. The regression coefficients for this model are given in Table 4 and the model displayed in Fig. 1. Interpretation of the regression coefficients is as follows: the positive coefficient for aspect indicates an increasing probability of finding a nest as the aspect increases towards 360°, the negative coefficient for slope reflects a declining probability of nest occurrence on flatter sites compared to sites on slopes. The habitat coefficient is the difference between the two predicted surfaces defined by aspect and slope and reflects a 3.5 times decline in the ratio of the odds (presence/absence) of a prediction for a drainage site compared with a

comparable slope site. Figure 1 shows the distribution of the observations in the multidimensional space defined by slope and aspect. The lines show where in that two dimensional space the model predicts selected probabilities of nest occurrence for given combinations of slope and aspect. Note that a predicted probability of 0.1 implies that for ten sites (for example slopes) with the same slope and aspect, one would expect one site to have *Aphaenogaster* nests; in contrast for a predicted probability of 0.5, five of the ten sites would be expected to have nests.

#### EDAPHIC VARIABLES

Textural variables, percent sand, gravel or clay for the A1 horizon or the B horizon showed a significant relationship with the presence of *A.*

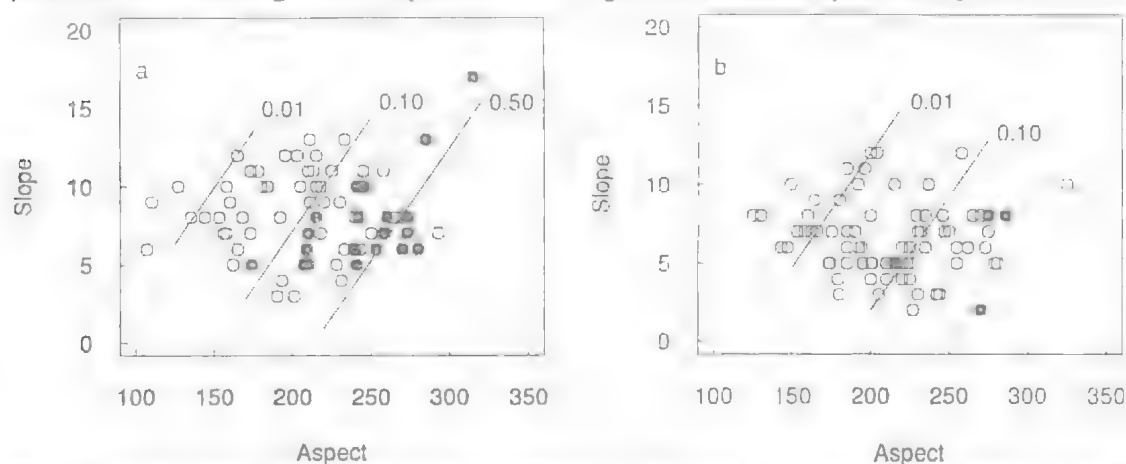


FIG. 1. Observed and predicted probabilities of occurrence of nests of *A. longiceps* as a function of aspect, expressed as degrees from north, for sites classified in the field as either slopes (a) or drainage lines (b). Sites are shown as solid symbols where nests were present and as open symbols where absent. Continuous lines show the predicted probability of nest occurrence.

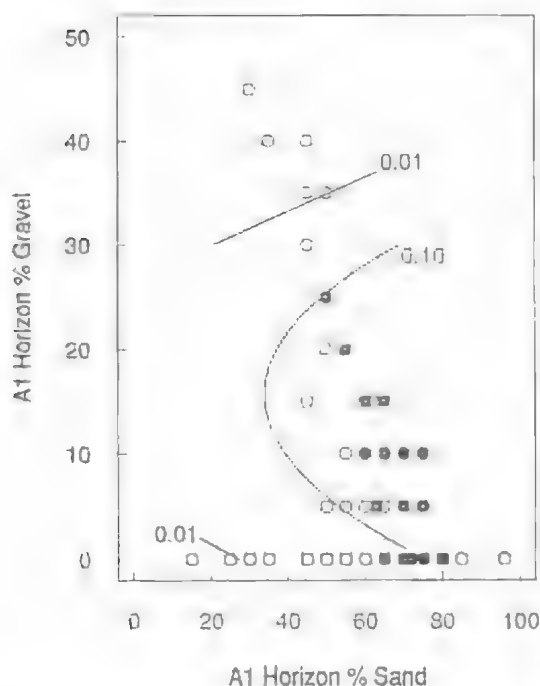


FIG 2. Distribution sites in the environmental space defined by percent gravel and percent sand. Sites are shown as solid symbols where nests were present and as open symbols where absent. Continuous lines show the predicted probability of nest occurrence.

*longiceps* nests (Table 5). The colour, expressed as the chroma (Munsell Color Company, 1971), of the A2 and B horizons showed less pronounced but significant relationships (Table 5). The final model was a quadratic function of the percent gravel of the A1 horizon plus a linear function of the percent sand of the A1 horizon (Table 6). For any given values of percent sand the maximum predicted probability of occurrence will be at about 15–16% gravel content. The predicted surface and observed data are shown as a function of these two variables (Fig. 2).

#### VEGETATIONAL VARIABLES

The vegetational characteristics fall naturally into three groups: litter, understorey components and the canopy. Significant relationships were found for litter and understorey components but not for canopy components (Table 7). Percent bare ground was the most significant litter component whereas percent grass cover was the most important single variable of the understorey group (Table 7). The selected model was a quadratic function of percent bare ground, linear func-

tion of percent moss cover and a linear function of percent grass cover (Table 8). Maximum probabilities are predicted for percent bare ground around 15%; the probability of occurrence declines with increasing cover of grass and moss. For moss cover the rate of decline of the odds ratio is about 1.6 times that for grass cover.

#### COMPARISON OF THE THREE MODELS

The three models can be compared informally in terms of the overall measure of lack of fit. For generalized linear models, this measure is usually referred to as the deviance (McCullagh & Nelder, 1989). Although for many generalized linear models the behaviour of the deviance is understood for models based on binary (that is presence or absence) data (such as used here) the behaviour is known not to have expected asymptotic properties. For this reason the use of the deviance as a measure of model adequacy is not recommended (McCullagh & Nelder, 1989). However, we can use it to rank the three final models; the topographic model had a residual deviance of 152 with 284 degrees of freedom; the vegetation model a deviance of 168 with 283 degrees of freedom; and the soil-based model a deviance of 190 with 284 degrees of freedom. The topographic-based model offers the greatest explanation of the observed variation in distribution of nests of *A. longiceps* and the vegetation model the least explanation.

#### DISCUSSION

Despite the rarity of occurrence of nests — present on 35 of the 288 quadrats (which were located on 25 of the 144 sites) — a wide range of environmental variables drawn from the three classes have significant relationships with the occurrence of *A. longiceps* nests (Tables 2, 5 & 7). This result reflects the likely collinearity of many of the environmental variables within the sample of sites used for monitoring the impact of fragmentation. Despite this, it is possible to draw some conclusions about the influence of environment on the distribution of *A. longiceps* within the local region of the Wog Wog habitat fragmentation experiment.

The site or topographic-based model demonstrates a clear preference of species for warm exposed (north-west facing) slopes (Fig. 1). In addition, the preference for sandy soils on warm slopes suggests that this species avoids wet conditions. As noted by Margules (1992) the

TABLE 3. Changes in deviance (a measure of the lack of fit used to assess logistic regression models fitted to binary data) when the topographic variables were added singly to the model containing the linear function on aspect. This table represents the results of the second pass of the forward stepwise fitting procedure.

Variable	d.f.	Deviance	d.f.	Deviance	P
Aspect	286	181.80			
+ Slope	285	180.30	1	1.502	>0.1
+ Slope+Slope <sup>2</sup>	284	180.25	1	0.049	>0.1
+ Aspect+Aspect <sup>2</sup>	284	178.45	1	3.353	0.067
+ Landform	278	147.07	8	34.730	<0.001
+ Habitat	285	160.99	1	20.815	<0.001
+ Catchment size	283	160.36	3	21.446	<0.001
+ Fire History	284	176.36	2	5.442	0.066
+ Water Erosion	285	176.90	1	4.898	0.027

TABLE 4. Regression coefficients and approximate standard errors for the final model relating probability of occurrence of nests of *A. longiceps* with selected topographic and site variables.

Variable	Parameter estimate	Standard error	t value	P
Intercept	-8.649	1.598	5.41	<0.001
Habitat	1.247	0.271	4.61	<0.001
Aspect	0.03468	0.00682	5.08	<0.001
Slope	-0.2407	0.0839	2.87	0.005

TABLE 5. Changes in deviance (a measure of the lack of fit used to assess logistic regression models fitted to binary data) when the edaphic variables were fitted singly to the null model. Textural components are abbreviated, sand = S, clay = C, and gravel = G. All continuous variables were fitted as both first and second order polynomial functions. Where no second order function is shown below it may be assumed that the change in deviance due to the addition of the quadratic term was not significant and was less than 2.

Variable	d.f.	Deviance	d.f.	Deviance	P
Null	287	213.10			
A horizon					
%S	286	209.60	1	3.49	0.062
%S + %S <sup>2</sup>	285	204.54	1	5.06	0.024
%C	286	205.14	1	7.96	0.005
%C + %C <sup>2</sup>	285	202.69	1	2.45	>0.1
%G	286	212.58	1	0.52	>0.1
%G + %G <sup>2</sup>	285	194.48	1	18.09	<0.001
A2 horizon					
Thickness	286	213.10	1	0.00	>0.1
Colour					
Hue	286	212.30	1	0.80	>0.1
Hue+Hue <sup>2</sup>	285	208.83	1	3.47	0.062
Value	286	212.06	1	1.04	>0.1
Chroma	286	204.69	1	8.41	0.004

TABLE 6. Regression coefficients and approximate standard errors for the final model relating probability of occurrence of nests of *A. longiceps* with selected edaphic variables. Residual deviance for this model was 190.05 with 284 degrees of freedom. Edaphic variables are abbreviated, % gravel as %G and % sand as %S.

Variable	Parameter estimate	Standard error	t value	P
Intercept	-5.9428	1.8491	3.21	0.002
A1 %G	0.2639	0.0680	3.88	<0.001
A1 %G + %G <sup>2</sup>	-0.00844	0.00305	2.77	0.007
A1 %S	0.0496	0.0258	1.93	0.057

TABLE 7. Changes in deviance (a measure of the lack of fit used to assess logistic regression models fitted to binary data) when the vegetation variables were fitted singly to the null model. All continuous variables were fitted as both first and second order polynomial functions. Where no second order polynomial function is shown below it may be assumed that the change in deviance due to the addition of the quadratic term was not significant and was less than 2.

Variable	d.f.	Deviance	d.f.	Deviance	P
Null	287	213.10			
% Bare grd	286	201.43	1	11.67	<0.001
% Bare grd <sup>2</sup>	285	188.94	1	12.49	<0.001
Litter					
% Leaf	286	212.29	1	0.81	>0.10
% Leaf <sup>2</sup>	285	209.02	1	3.27	0.071
% Bark	286	209.57	1	3.52	0.061
% Bark <sup>2</sup>	285	208.37	1	1.21	>0.10

TABLE 8. Regression coefficients and approximate standard errors for the final model relating probability of occurrence of nests of *A. longiceps* with selected vegetation variables.

Variable	Parameter estimate	Standard error	t value	P
Intercept	-1.2785	0.4434	2.88	0.004
% Bare ground	0.3249	0.1254	2.59	0.010
% Bare ground <sup>2</sup>	-0.0110	0.0072	1.52	>0.10
% Moss	-0.0972	0.0428	2.27	0.024
% grass	-0.0596	0.0267	2.34	0.026

experimental site was selected such that the layout of the remnants was on a predominantly south western facing slope. Despite this, the local relief within the experimental site causes aspects for the 144 monitoring sites to range from 107° to 325° with the majority between 185° and 240°. There is little difference between those monitoring points classified as slopes and those as drainage lines in terms of the range of aspects nor in terms of their slope. There is little correlation between site aspect and slope (Fig. 1). The impact of fragmentation of the forest will not change the aspect or slope of the monitoring sites although the exposure of sites can increase due to the loss of surrounding forest canopy. This can be most

noticeable for sites close to the edges of the remnants and may change the range of effective exposure, increasing it for westerly aspects and perhaps decreasing it for southerly aspects. Given the preference of *A. longiceps* for nesting on westerly to north-westerly (=warm) sites and the potential for increased exposure following forest canopy fragmentation, the response of this ant to the direct impact of fragmentation will be to maintain or perhaps to increase its current rate of site occupancy.

The strong influence of surface texture on the probability of nest occurrence is consistent with the usual statements about the preference of *Aphaenogaster* spp. for sandy soils (Sloane &

Sloane, 1964; Saunders, 1967; Andersen, 1991). Although the best model includes the A1 horizon sand content, it also contains the gravel content of that layer, a point not noted in the literature. Neither of these two variables are likely to change dramatically due to the fragmentation treatment. The question of collinearity within the data matrix is important because the soils with high clay content tend to dominate the gullies. Total separation of the influence of surface texture from that of topography might not be possible without more extensive sampling. Although a formal test of the difference between the two models has not been undertaken, the site-based model appears to offer better predictive ability than the soil-based model.

The interpretation of the final vegetation-based model is less clear because more variables are included and these show more correlation than one would like when undertaking this type of modelling exercise because of the difficulty of separating the influence of individual variables when there is high collinearity. Also, these variables can themselves respond to the impact of fragmentation of the forest. Increased exposure — particularly around the edges and perhaps over all of the small remnants — may result in a loss of moss cover and a reduction in grass cover. This could lead to an increase in bare ground, one of the important predictor variables in this model. Such changes, if they occur, may lead to an increase in favourable nest sites because the probability of occurrence is negatively correlated with both moss and grass cover.

It should be noted that there are substantial differences in the distribution of moss cover on the slopes in contrast to the drainage lines. The inclusion of moss cover in the model as a predictor might be the result of this difference. Frequent and high moss cover is characteristic of drainage lines; as such, it may be acting as a surrogate for the habitat variable noted as an important predictor in the site-based model rather than the ants responding directly to the extent of moss cover.

On the basis of the three independently fitted models, the dominant influences on the distribution of nests of *A. longiceps* appear to be those that are not likely to change following the clearing of the surrounding forest to create habitat remnants. This suggests that the fragmentation treatment imposed on this eucalypt forest is unlikely to have a direct impact on the distribution of *A. longiceps* nests. This is not in conflict with the concern expressed by Sloane & Sloane (1964) with the impact of habitat loss on *A. longiceps*.

The prediction that fragmentation will not result in a reduced rate of site occupancy will be tested in two ways and the results reported elsewhere. A re-survey of the quadrats is planned for the spring or summer of 1993/94. This would be directly comparable to the 1987 survey and nest loss could be determined and related to the isolation treatment, habitat remnant size and position within the remnant. A second test of the prediction will be based on changes in distribution and relative population size of *A. longiceps* caught in pitfall traps operated quarterly for the duration of the experiment (Margules, 1992).

#### ACKNOWLEDGEMENTS

Thanks are due to M.P. Austin for assistance with the collection of the environmental data, and to C. James, C.R. Margules, J.A. Meyers and D. Spratt for critical comment on an earlier MS.

#### LITERATURE CITED

- ADLER, G.H. & WILSON, M.L. 1985. Small mammals on Massachusetts Islands: the use of probability functions in clarifying biogeographic relationships. *Oecologia* (Berlin) 66: 178-186.
- ANDERSEN, A.N. 1991 'The ants of southern Australia. A guide to the Bassian fauna'. (CSIRO: Melbourne).
- AUSTIN, M.P., CUNNINGHAM, R.B. & FLEMING, P.M. 1984. New approaches to direct gradient analysis using environmental scalars and statistical curve-fitting procedures. *Vegetation* 55: 11-27.
- AUSTIN, M.P., CUNNINGHAM, R.B. & GOOD, R.B. 1983. Altitudinal distribution of several eucalypt species in relation to other environmental factors in southern New South Wales. *Australian Journal of Ecology* 8: 169-180.
- AUSTIN, M.P. & NICHOLLS, A.O. 1988. Species associations within herbaceous vegetation in an Australian Eucalypt forest. Pp. 95-114. In During, H.J., Werger, M.J.A. & Willems, J.H. (eds). 'Diversity and pattern in plant communities'. (SPB Academic Publishing: The Hague).
- AUSTIN, M.P., NICHOLLS, A.O. & MARGULES, C.R. 1990. Measurement of the realized qualitative niche: environmental niches of five *Eucalyptus* species. *Ecological Monographs* 60: 161-177.
- COLLETT, D. 1991. 'Modelling binary data'. (Chapman and Hall: London).
- GREENSLADE, P.J.M. 1974. Distribution of two

- forms of the meat ant, *Iridomyrmex purpureus* (Hymenoptera: Formicidae), in parts of South Australia. Australian Journal of Zoology 22: 489-504.
1976. Distribution of two forms of the meat ant *Iridomyrmex purpureus* (Hymenoptera: Formicidae) on Kangaroo Island and in the Yorke Peninsula. Australian Journal of Zoology 24: 557-574.
1985. Some effects of season and geographical aspect on ants (Hymenoptera: Formicidae) in the Mt Lofty Ranges, South Australia. Transactions of the Royal Society of South Australia 109: 17-23.
1987. Environment and competition as determinants of local geographic distribution of five meat ants, *Iridomyrmex purpureus* and allied species (Hymenoptera: Formicidae). Australian Journal of Zoology 35: 259-273.
- HOSMER, D.W. & LEMESHOW, S. 1989. 'Applied logistic regression'. (John Wiley and Sons: New York).
- LINDENMAYER, D.B., CUNNINGHAM, R.B., TANTON, M.T., NIX, H.A. & SMITH, A.P. 1991a. The Conservation of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria, south-east Australia: III. The habitat requirements of Leadbeater's Possum *Gymnobelideus leadbeateri* and models of the diversity and abundance of arboreal marsupials. Biological Conservation 56: 295-315.
- LINDENMAYER, D.B., CUNNINGHAM, R.B., TANTON, M.T., SMITH, A.P. & NIX, H.A. 1991b. Characteristics of hollow-bearing trees occupied by arboreal marsupials in the montane ash-forests of the Central Highlands of Victoria, south-east Australia. Forest Ecology and Management 40: 289-308.
- MACARTHUR, R.H. & WILSON, E.O. 1967. 'The theory of island biogeography'. (Princeton University Press: New Jersey).
- MARGULES, C.R. 1992. The Wog Wog habitat fragmentation experiment. Environmental Conservation 19: 316-325.
- MCCULLAGH, P. & NELDER, J.A. 1989. 'Generalized linear models'. (Chapman and Hall: London).
- MUNSELL COLOR COMPANY 1971. 'Munsell soil color charts'. (Munsell Color Company: Baltimore, Maryland).
- NICHOLLS, A.O. 1989. How to make biological surveys go further with generalized linear models. Biological Conservation 50: 51-75.
- SAUNDERS, G.W. 1967. Funnel ants (*Aphaenogaster* spp., Formicidae) as pasture pests in North Queensland. I. Ecological background, status and distribution. Bulletin of Entomological Research 57: 419-432.
- SLOANE, H. & SLOANE, A.I. 1964. The trap-nest or sand ant. Victorian Naturalist 81: 165-167.



# AN OVERVIEW OF MODELLING FINE-SCALE VARIATION IN ENVIRONMENTAL REGIMES IN COMPLEX LANDSCAPES WITH COMMENTS ON APPLICATIONS TO INVERTEBRATE SURVEY, MONITORING AND CONSERVATION

T.W. NORTON

Norton, T.W. 1994 06 30: An overview of modelling fine-scale variation in environmental regimes in complex landscapes with comments on applications to invertebrate survey, monitoring and conservation. *Memoirs of the Queensland Museum* 36(1): 173-177, Brisbane. ISSN 0079-8835.

Spatial and temporal variation in environmental regimes such as thermal, radiation and hydrologic conditions can influence invertebrates in many ways including the survival and performance of species, their biogeography, patterns of alpha and beta diversity, and their role in various essential ecosystem processes. Combinations of environmental regimes are known to be significant determinants of habitat quality for many invertebrates but, until recently, the technical ability to model fine-scale environmental heterogeneity in the landscape has been limited. In this paper I discuss some recent developments in modelling environmental heterogeneity at scales apparently sufficient to provide habitat discrimination for a number of invertebrate taxa, and comment on the potential application of these techniques to invertebrate biodiversity conservation. □ *Invertebrates, biodiversity, conservation, environmental gradient, predictive modelling, geographic information system, conservation reserve network.*

T.W. Norton, Centre for Resource and Environmental Studies, Institute of Advanced Studies, The Australian National University, Canberra ACT 0200, Australia; 16 August 1993.

Australia signed the Convention on Biological Diversity on World Environment Day in 1992, at the Earth Summit in Rio de Janeiro, and ratified it on 18 June 1993. The convention was developed in recognition of the present and future value of biological diversity and its significant reduction around the world. The intention of the Convention is to be a powerful catalyst for drawing together existing issues to protect biological diversity and to provide strategic direction to global efforts in this area (DEST, 1993).

Many approaches can be adopted for the conservation of biological diversity. The general approach adopted in many nations involves, in principle, the use of conservation reserves complemented by off-reserve management practices (e.g. codes of practice) that aim to minimise significant detrimental impacts on biological diversity. Where necessary, additional measures such as ex-situ conservation and the reintroduction and translocation of species may be used to support conservation objectives. For this general conservation strategy to be effective, it is important that (i) the reserve system be representative of the full range of biological diversity in the nation of concern, (ii) the reserve system be sufficiently comprehensive and adequate to be viable over at least the medium term, (iii) off-reserve management prescriptions be sufficiently conservative to allow for uncertainties arising from limited

biological knowledge; and (iv) research and ecological monitoring programs be in place so that it is possible to learn from the successes and failures of various management prescriptions (Common & Norton, 1993). A number of new programs have been initiated nationally and internationally to address these needs, including the National Reserves System Cooperative Program (NRSCP) which involves the progressive establishment of a comprehensive national system of protected areas in Australia by the year 2000.

Because scientific knowledge of most taxa and assemblages is limited, the selection of additional conservation reserves will typically be based on environmental data and limited biological data. The latter data will primarily be for vascular plants and vertebrate fauna. Given this, three important questions arise regarding invertebrate biodiversity conservation:

(1) to what extent can environmental, vegetation and vertebrate fauna data be reliably used as surrogates for data on invertebrate biodiversity?

(2) is it possible to determine which invertebrate taxa might be well and poorly represented by such data?

(3) given the above, what is the most effective way of enhancing the effectiveness of invertebrate biodiversity conservation in the short, medium and long term?

The purpose of this paper is to discuss the potential for applying spatial modelling techniques that have been developed to characterise environmental regimes at various spatial scales to invertebrate biodiversity surveys and conservation evaluation.

#### MODELLING ENVIRONMENTAL REGIMES IN COMPLEX LANDSCAPES

One aim of ecology is to better understand the biological patterns, particularly the distribution and abundance of taxa, that occur within terrestrial ecosystems and the processes that effect these patterns. By enhancing this understanding data on biota will be acquired that can be used immediately for conservation planning and management. In addition, these data can be used to improve ecological theory and help develop a process based understanding of natural systems to permit the more reliable prediction of system dynamics.

The concepts underlying the spatial modelling of environmental regimes and their use for developing a process understanding of biological systems have been well discussed by Nix & Gillison (1985), Norton et al. (1990) and Moore et al. (1993). Contemporary studies of the processes effecting the distribution, productivity and interactions between biota along environmental gradients are likely to be more informative if these gradients are characterized more specifically and at a finer resolution than has typically been employed in the past. For example, rather than using elevation as a crude surrogate for spatial variation in temperature and/or precipitation in a region, it is more accurate to employ quantified gradients of these and other climatic attributes associated with elevation to model biological patterns. Similarly, rather than using estimates of spatial variation in mean annual temperature or rainfall, for example, as variables to model the distribution of taxa, it is more realistic to use climatic indices that more closely reflect the ambient conditions to which species are exposed (see Margules & Austin, 1991). This is now possible at a fine spatial scale using modern computer-based mathematical algorithms and spatial analysis techniques, coupled to spatially-related data sets including digital terrain models, to derive estimates of climate surfaces and various site attributes or indices of environmental processes that are considered indicative of landscape processes (Moore et al., 1993). Some of the environmental regimes that can be modelled in-

clude the surface energy budget (evapotranspiration, potential solar radiation); minimum, maximum and average air temperature, wind speed and wind run; relative soil water content or wetness index; soil mineral nutrients; hydrological properties of a catchment (e.g. rates of discharge and recharge); and, the potential biological productivity of a site.

Central to this modelling is an ability to derive reliable estimates of the terrain, climate, and substrate for large regions at relatively fine scales, and to manipulate and analyse these data quickly and efficiently. Digital elevation models (DEMs) have been developed by Hutchinson (1989) to interpolate topographic data and model spatial variation in terrain. The data used to develop these models can be in the form of (digitised) irregularly spaced point elevation data, major streamlines, natural sinks (eg. lakes) and the coastline. The techniques have been used to generate a continental DEM for Australia at a grid resolution of 1/40th degree longitude and latitude ( $2.5 \times 2.5$  km) (Hutchinson & Dowling, 1991). DEMs at finer resolutions (i.e. a gridded database where each grid cell represents from  $250 \times 250$  m down to  $1 \times 1$  m on the ground) have been developed for several regions of the Australian continent for specific survey, inventory and land evaluation studies (e.g. Richards et al., 1990; Moore et al., 1993). Digital terrain models can be derived from a DEM to allow an estimate of slope, aspect and related topographic features of a landscape for each grid cell (Moore et al., 1991). These models and spatially related data sets are held with a geographical information system.

Climate surface fitting techniques developed by Hutchinson (1987) have enabled the estimation of spatially reliable mean (monthly, weekly, daily) climate attributes derived from long-term meteorological station records for any given longitude, latitude and elevation on the Australian continent and selected other regions. The errors associated with these estimates are typically of the same order as those associated with observer and instrument errors.

Currently, techniques to estimate spatial variation in soil fertility are limited as soils data are not available at compatible resolutions for most of the Australian continent. Geological data mapped at a scale of 1:250 000 represents the best data available to estimate soil nutrient regimes at a landscape level, although soils data may be available for a number of areas. Mackey et al. (1988, 1989) reported a procedure to derive a spatial estimate of soil nutrient availability for relatively

large regions by assigning a rating (0-10) to each lithological unit digitised from geological maps for a given region. The major assumption with this technique is that the soils in the specified region are largely derived from the parent material below and not formed through depositional processes, in which case the soils may be unrelated to the composition of the underlying bedrock.

Several additional data sets such as vegetation cover, data on the distribution of wildlife and site disturbance have been found to be useful for the survey, inventory, and management of various plant and animal taxa (Richards et al., 1990; Margules & Austin 1991; Nix & Switzer, 1991; Neave et al., 1992).

#### APPLICATIONS OF MODELLING TECHNIQUES

A number of applications of the techniques developed for modelling environmental regimes in complex landscapes have been published recently (see Neave & Norton, 1991). These applications include the characterisation of the spatial and temporal variation in the environmental regime of landscapes as a basis for the design (e.g. stratification) of biological surveys, and the undertaking of biological modelling and conservation evaluation. For example, Austin & Heyligers (1989) outlined a systematic procedure using derived environmental regimes to stratifying the location of sites for the field survey and inventory of vascular plants in north east New South Wales. Similar approaches have been developed by Neave et al. (1992) for the inventory of diurnal birds in south east Australia, and Moore et al. (1993) in the Brindabella Range, Australian Capital Territory for characterising the realised niche of eucalypts.

Environmental regimes estimated for large regions were employed by Norton & Williams (1990), Lindenmayer et al. (1991), and Norton et al. (1992) to assist in the systematic collection of site-based data for building predictive models of the distribution of vertebrate fauna. In addition, this general approach has been suggested for assessing the potential viability of existing or proposed wildlife corridors under scenarios of global and climate change (Norton & Nix, 1991).

Booth et al. (1988) have used these techniques to quantify the realised niche of tree species to help in the identification of new sites best suited to grow species/genotypes or to identify the most suitable taxa to grow at a particular site (e.g.

Booth et al., 1988). Mackey (1991) predicted the spatial variation in forest architecture and physiognomy of tropical rainforest vegetation in north east Queensland, Australia using this approach, while Nix et al. (1992) employed spatial estimates of environmental regimes and other site attributes to predict variation in site productivity and the rate of growth of eucalypts in Tasmania. It should be noted, however, that most of the above studies concern vascular plants, vertebrates and assemblages thereof. The use of these techniques for invertebrate conservation is limited (P. Cranston & M. Gray, pers. comm., 1993) but, I believe, has significant promise.

#### ROLE OF SPATIAL MODELLING FOR INVERTEBRATE CONSERVATION

Spatial and temporal variation in environmental regimes such as thermal, radiation and hydrologic conditions may influence invertebrates in many ways including the survival and performance of species, their biogeography, and patterns of alpha and beta diversity (Warren, 1985; Dobkin et al., 1987; Weiss et al., 1988; Kitching et al., 1993). Combinations of environmental regimes are known to significantly influence the habitat quality of many taxa but, until recently, the technical ability to model fine-scale environmental heterogeneity in the landscape has been limited.

It is now possible to estimate various environmental regimes at a fine spatial scale, across large areas. Moore et al. (1993), for example, modelled various environmental regimes (e.g. net radiation; maximum, average and minimum temperature; precipitation, soil water content, evapotranspiration) in a 21 km<sup>2</sup> area in the sub-alpine forests in south east Australia using gridded data where each grid cell represented 20 × 20 m on the ground. The authors used these data to investigate the environmental correlates of vegetation in the study area and found the average minimum temperature in the coldest month and the annual net radiation were two environmental variables differentiating the occurrence of several of the major tree species. More recently, this database has been extended to cover an area of 90 km<sup>2</sup>. Gridded environmental databases with a cell size of 100-200 m exist for large regions including the wet tropics of north east Queensland, north eastern New South Wales and Tasmania. As a consequence it is now possible to investigate the extent to which these modelling approaches can be usefully applied for inver-

tebrate biodiversity conservation. In particular, can environmental gradients in major environmental regimes be used to help design field surveys that are more effective in capturing the range of invertebrate biodiversity within target areas, or to monitor changes in invertebrate assemblages over time? Can these techniques be used to develop correlative models for predicting the distribution of invertebrate taxa?

As these sorts of issues are addressed it will be possible to quantitatively consider the three questions that I raised at the outset of this paper. It will be possible to test the extent to which patterns exhibited by plants and vertebrate taxa are congruent with those observed for invertebrates, and to establish the most appropriate scales at which to use these techniques for survey, analysis, conservation evaluation and management. In the context of invertebrate biodiversity conservation, a significant management question will presumably be how to proceed if the present surrogates (e.g. vegetation, vertebrates) that are used for conservation reserve selection and configuration are found to be completely inadequate. If this is the case, then appropriate off-reserve management will be very important requirement in the overall effort to conserve invertebrate biodiversity.

#### LITERATURE CITED

- AUSTIN, M.P. & HEYLIGERS, P.C. 1989. Vegetation survey design for conservation: gridsect sampling of forests in north-eastern New South Wales. *Biological Conservation* 50: 13-32.
- BOOTH, T.H., NIX, H.A., HUTCHINSON, M.F. & JOVANOVIĆ, T. 1988. Niche analysis and tree species introduction. *Forest Ecology and Management* 23: 47-59.
- COMMON, M.S. & NORTON, T.W. 1993. Biodiversity conservation, natural resource accounting and ecological monitoring. Pp. 81-103. In 'Biodiversity conservation'. (Kluwer Academic Press: London).
- DEST (DEPARTMENT OF THE ENVIRONMENT, SPORT & TERRITORIES) 1993. 'International Biodiversity Convention'. (AGPS: Canberra).
- DOBKIN, D.S., OLIVIERA, L. & EHRLICH, P.R. 1987. Rainfall and the interaction of microclimate with larval resources in the population dynamics of checkerspot butterflies (*Euphydryas editha*) inhabiting serpentine grassland. *Oecologia* 71: 161-166.
- HUTCHINSON, M.F. 1987. Methods for generation of weather sequences. Pp. 149-157. In Bunting A.H. (ed.), 'Agricultural environments: characterisation, classification and mapping' (CAB International: Wallingford).
1989. Calculation of hydrologically sound digital elevation models. Pp. 117-133. In 'Proceedings Third International Symposium for Spatial Data Handling'. (International Geographical Union: Colombo).
- HUTCHINSON, M.F. & DOWLING, T. 1991. A continental hydrological assessment of a new grid-based digital elevation model of Australia. *Hydrological Processes* 5: 45-58.
- KITCHING, R.L., BERGELSON, J.M., LOWMAN, M.D., MCINTYRE, S. & CARRUTHERS, G. 1993. The biodiversity of arthropods from Australian rainforest canopies: general introduction, methods, sites and ordinal results. *Australian Journal of Ecology* 18: 181-191.
- LINDENMAYER, D.B., NIX, H.A., MCMAHON, J.P., HUTCHINSON, M.F. & TANTON M.T. 1991. The conservation of Leadbeater's Possum, *Gymnobelideus leadbeateri* (McCoy): a case study of the use of bioclimatic modelling. *Journal Biogeography* 18: 371-383.
- MACKEY, B.G. 1991. 'The spatial extension of vegetation site data: a case study in the rainforests of the Wet Tropics of Queensland, Australia.' (Unpublished Ph.D. Thesis, Australian National University, Canberra).
- MACKEY, B.G., NIX, H.A., HUTCHINSON, M.F., MCMAHON, J.P. & FLEMMING, P.M. 1988. Assessing representativeness of places for conservation reservation and heritage listing. *Environmental Management* 12: 501-514.
- MACKEY, B.G., NIX, H.A., STEIN, J.A., CORK, S.E. & BULLEN, F.T. 1989. Assessing the representativeness of the Wet Tropics of Queensland World Heritage Property. *Biological Conservation* 50: 270-303.
- MARGULES, C.R. & AUSTIN, M.P. (eds) 1991. 'Nature conservation: cost effective surveys and data analysis'. (CSIRO: Canberra).
- MOORE, I.D., GRAYSON, R.B. & LADSON, A.R. 1991. Digital terrain modelling: a review of hydrological, geomorphological and biological applications. *Hydrological Processes* 5: 3-30.
- MOORE, I.D., NORTON, T.W. & WILLIAMS, J.E. 1993. Modelling environmental heterogeneity in forested landscapes. *Journal of Hydrology* 150: 717-747.
- NEAVE, H.M., CUNNINGHAM, R.B., NORTON, T.W. & NIX, H.A. 1992. Evaluation of sampling strategies for estimating species richness by Monte Carlo methods. *Mathematics and Computers in Simulation* 33: 391-396.
- NEAVE, H.M. & NORTON, T.W. 1991. Integrated management of forest wildlife: comments on new ways to research habitat. Pp. 229-236. In Lunney, D. (ed.), 'Conservation of Australia's forest fauna' (Royal Zoological Society of NSW: Sydney).
- NIX, H.A. & GILLISON, A.N. 1985. Towards an operational framework for habitat and wildlife management. Pp. 39-55. In Kikkawa, J. (ed.), 'Wildlife management in the forests and forestry-

- controlled lands in the Tropics and Southern Hemisphere (University of Queensland: Brisbane).
- NIX, H.A., STEIN, J.A. & STEIN, J.L. 1992. 'Developing an environmental geographic information system for Tasmania. An application to assessing the potential for hardwood plantation forestry.' (Land Resources Division and Bureau of Rural Resources, Federal Department of Primary Industries and Energy, Canberra).
- NIX, H.A. & SWITZER, M. 1991. 'Atlas of vertebrates endemic to Australia's Wet Tropics. Kowari Series No. 1.' (Australian National Parks and Wildlife Service and AGPS: Canberra).
- NORTON, T.W., MACKEY, B.G. & LINDEN-MAYER, D.B. 1990. Comments on biological and environmental data sets required for the Australian National Forest Inventory. *Australian Forestry* 53: 88-95.
- NORTON, T.W., NEAVE, H.M., NIX, H.A. & MOORE, I.D. 1992. Approaches to forest survey, inventory, evaluation and planning using biophysical models of landscape processes. Pp. 1-7. In 'Proceedings of GIS '92, Vancouver'. (British Columbia: Canada).
- NORTON, T.W. & NIX, H.A. 1991. Application of biological modelling and GIS to identify regional wildlife corridors. Pp. 19-26. In Saunders D.A. & Hobbs, R.J. (eds), 'Nature conservation 2: The role of corridors' (Surrey Beatty & Sons in association with CSIRO: Sydney).
- NORTON, T.W. & WILLIAMS, J.E. 1990. Wildlife management in Australia: new developments and opportunities using computer-based generic models. *Mathematics and Computers in Simulation* 32: 231-235.
- RICHARDS, B.N., BRIDGES, R.G., CURTIN, R.A., NIX, H.A., SHEPHERD, K.R. & TURNER, J. 1990. 'Biological Conservation of the South-East Forests' (AGPS: Canberra).
- WARREN, M.S. 1985. The influence of shade on butterfly numbers in woodland rides, with special reference to the wood white (*Leptidea synapsis*). *Biological Conservation* 33: 147-164.
- WEISS, S.B., MURPHY, D.D. & WHITE, R.R. 1988. Sun, slope and butterflies: topographic determinants of habitat quality for *Euphydryas editha*. *Ecology* 69: 1486-1496.

## INBREEDING DEPRESSION IN AUSTRALIAN BUTTERFLIES: SOME IMPLICATIONS FOR CONSERVATION

A.G. ORR

Orr, A.G. 1994 06 30: Inbreeding depression in Australian butterflies: some implications for conservation. *Memoirs of the Queensland Museum* 36(1): 179-184. Brisbane. ISSN 0079-8835.

Inbreeding depression in butterflies is manifested in many ways, including egg inviability, retarded larval development and premature mortality, failure to complete pupation and increased mortality during the pupal stage and at eclosion, and reduction in size of adults with an associated loss of vigour and reduced fecundity. Of the species examined, inbreeding depression was most severe in Papilionidae, especially the troidines *Cressida cressida* (Fabricius) and *Ornithoptera richmondia* (Gray), and in the papilionine *Papilio aegeus* (Donovan). In *C. cressida*, hatching rates from matings between full siblings averaged about 40% and very few larvae survived to adulthood, whereas hatching rates from presumed outbred matings were nearly 100%. Hatching rates from full sibling matings in *O. richmondia* and *P. aegeus* were about 70% and declined sharply as the coefficient of inbreeding was increased. In other species tested, papilionids *Chilasaanactus* (W.S. Macleay) and *Graphium macleayanum* (Leach), the pierid *Delias nigrina* (Fabricius) and the nymphalids *Danaus affinis* (Fabricius) and *Tellervo zoilus* (Fabricius), inbreeding depression was either not detected or was not apparent until the inbreeding coefficient exceeded 0.5. Inbreeding depression may be more severe in wide ranging species with an open population structure, and it is evident that given the severity of inbreeding depression recorded in troidine species such as *Ornithoptera richmondia*, it is necessary to conserve adequate habitat to maintain viable populations. Evidence is presented of inbreeding in wild *O. richmondia*. □ *Butterflies, conservation, captive breeding, inbreeding depression, Papilionidae.*

A.G. Orr, Department of Biology, Universiti Brunei Darussalam, Gadong 3186. Brunei. 12 July 1993.

Deleterious effects of inbreeding in organisms as diverse as white mice, *Drosophila* and cultivated maize are well known (Falconer, 1981; Wright, 1977). Typically, reproductive processes and early development are most affected (Frankel & Soulé, 1981). In holometabolous insects, ways in which inbreeding depression can be expressed include reduction in size of adult progeny and reduced fecundity, retarded larval development and failure to pupate or eclose successfully. More severe cases may suffer premature death in larval stages or in the egg, sometimes very early in embryogenesis (Clayton et al., 1957; Wallace & Madden, 1965; Wright, 1977).

Despite extensive breeding programmes for scientific and commercial purposes, inbreeding depression has seldom been reported in butterflies. In a survey of case histories of extinctions, Ehrlich (1983) concluded that stochastic demographic factors caused extinction long before inbreeding would have had a chance to take effect. Ehrlich's sample may have been unrepresentative since he considered mostly localised species from relatively closed populations (Ehrlich, 1965; Gilbert & Singer, 1973) inhabiting temperate, highly seasonal environ-

ments and frequently subject to catastrophic mortality due to adverse weather (Ehrlich et al., 1972, 1980).

In general, inbreeding depression would most likely be severe in wide ranging species which habitually outbreed, either because their open population structure has allowed accumulation of deleterious alleles or because they have been selected for a mating system which maximises outbreeding because of the effects of inbreeding. In either case, in the short time allowed to adjust to human alteration of the environment, species subject to severe inbreeding depression will need on average larger minimum viable populations. That means larger areas of suitable habitat. They will also generally be more sensitive to habitat fragmentation. Although the degree to which they are affected will depend on their ability to disperse, especially across tracts of unfavourable habitat. Inbreeding depression may also tend to be a more significant factor in extinctions of tropical species, many of which habitually exist at low population levels and may often pass through prolonged bottlenecks (Owen, 1971; Wolda, 1978) but are probably not normally sub-



ject to catastrophic density independent mortality.

I here investigate the effects of inbreeding in laboratory crosses in eight species of tropical butterflies. Species chosen are common and widespread but knowledge of their inbreeding susceptibilities may suggest possible risks in related vulnerable species.

## MATERIALS AND METHODS

Species studied were *Ornithoptera richmondia* (Gray), *Cressida cressida* (Fabricius), *Papilio aegaeus* Donovan, *Chilasa anactus* (W.S. Macleay), *Graphium macleayanum* (Leach) (all Pierionidae), *Delias nigrina* (Fabricius) (Pieridae), *Danaus affinis* (Fabricius) and *Tellervo zollus* (Fabricius) (Nymphalidae), and were selected because wild material was readily available for captive breeding and, in most cases, data were available on population structure based on mark-release-recapture (MRR) data.

For all species, 5-10 mated females were collected from the wild and allowed to oviposit on their host plants in a 2.5 x 3 x 4m flight cage. These females had presumably mated with an unrelated male. Eggs were collected from each female as they were laid and 10-20 larvae were reared to adulthood on appropriate hostplant. From these progeny, at least one brother-sister mating was arranged among the progeny of each original female. Matings were allowed to take place in the flight cage. That avoided handpairing which might have interfered with normal reproductive processes. The first 50 or 100 eggs produced by each consanguineously mated female were collected as they were laid, and the hatching rate was monitored. Any eggs which did not hatch or show other external signs of development (like darkening after sclerotization of head capsule) were dissected and examined microscopically to check for an embryo, indicating the egg was fertile. A subsample of hatching eggs (usually 50-100) including roughly equal numbers from each of the inbred matings was reared to adulthood and survival recorded. Forewing lengths of surviving adults were measured and compared with the midparent value.

More extensive data were obtained for *Cressida cressida* and *O. richmondia*. For *C. cressida*, initial stock was provided by 10 wild caught females (presumed outbred). From their progeny four inbred sib-sib matings each were arranged, and 100 eggs collected from each female, in total 400 eggs. All hatching larvae were raised until

they died or pupated and developmental times were recorded. Successfully eclosing adults (with inbreeding coefficient  $F=0.25$ ) from six of the ten original lines were mated: 1, with their sibs; and 2, with the inbred progeny from other lines. Hatching rates of samples of 100 eggs per female were recorded and all larvae were raised as far as possible. From resulting progeny ( $F=0.44$ ), three unrelated pairs of siblings were mated with each other and hatching rates recorded. Two pairs from different lines were crossed and hatching rates recorded. Similar data were obtained for *O. richmondia*, based on an initial stock of five wild females, five inbred pairs per generation, and samples of 50 eggs.

For *Tellervo zollus*, the offspring of four females were inbred for four generations, selecting one pair from each line each generation. Hatching rates, larval survival and developmental rates, and adult sizes were recorded as above. Also, the lifetime fecundity of subsamples of females was recorded.

## RESULTS

1. *Cressida cressida*: Hatching rates of eggs laid by wild females were all high, ranging from 97-100% ( $n=100$ ), as was larval survivorship (89%,  $n=100$ ) (Fig. 1). Hatching rates of eggs with an inbreeding coefficient ( $F_{\text{offspring}}$ ) of 0.25 ranged from zero to 79% with a mean of 43%. Larvae which hatched frequently showed retarded growth (Fig. 2), particularly in early instars, and survivorship to adult stage was low, averaging 7.3% of eggs hatching. Developmental times ranged from 21-47 days (mean, 33 days), considerably longer than the normal develop-

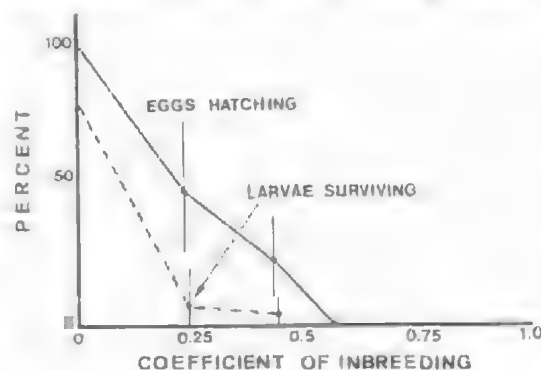
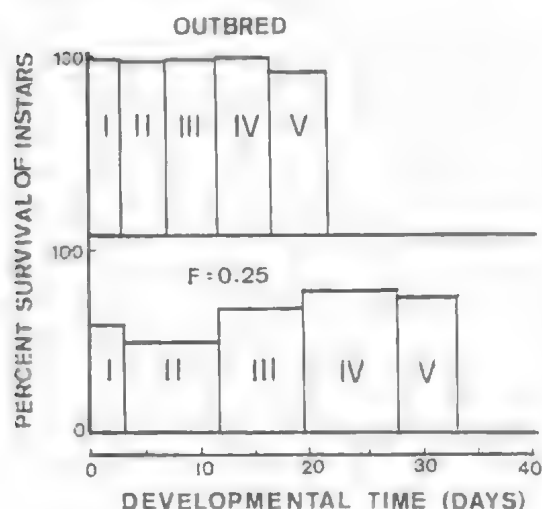


FIG. 1. Effects of increasing levels of inbreeding on hatching rate of eggs (solid line), and survival of hatching larvae (dashed line) in *Cressida cressida*. Vertical bars indicate standard deviations.



TABLE 1. Hatching rates and larval survivorship from inbred matings in five butterfly species. In all cases coefficient of inbreeding equals 0.25.

Species	<i>Papilio aegeus</i>	<i>Chilasa anactus</i>	<i>Graphium macleayanum</i>	<i>Delias nigrina</i>	<i>Danaus affinis</i>
Total number of inbred matings	10	5	6	8	5
Mean hatching rate & total [n]	69% [500]	97% [250]	96% [300]	99% [500]	98% [250]
Mean larval survivorship [n]	32% [50]	87% [60]	92% [50]	82% [120]	85% [45]

FIG. 2. An inbred cohort of *Cressida cressida* larvae which hatched on the same day. The fourth instar (at right) had developed normally while its three siblings were still in the second instar.FIG. 3. Larval survival and rate of development by instar in inbred ( $F=0.25$ ) and outbred *Cressida cressida*.

mental time of 21 days in outbred larvae (Fig. 3). In total, of 125 adults bred from 4000 eggs, seven were obviously stunted but the remainder were of normal size, robust and healthy. When these F1 adults were mated with their siblings (6 unrelated pairs,  $F_{\text{offspring}} = 0.44$ ), hatching rates were very low, ranging from zero to 38% (mean = 22%), and

larval survivorship was 5.9% of hatching eggs (13 adults from 600 eggs). When these F2 adults were mated (2 pairs,  $F_{\text{offspring}} = 0.58$  with siblings the hatching rate of eggs was zero. When the inbred F1 adults were crossed out, the hatching rate of eggs was nearly normal (95%,  $n=500$ , 5 pairs). The survival of larvae was not monitored for these matings.

2. *Ornithoptera richmondia*: Slightly less spectacular but nevertheless severe inbreeding effects were recorded in *O. richmondia* (Fig. 4). Hatching rates of presumed outbred eggs from wild females were 97% ( $n=500$ ) and larval survival was 82% ( $n=100$ ). Hatching rates of eggs from sibling crosses ( $F_{\text{offspring}} = 0.25$ ) ranged from 62 to 84% (mean = 74%). Larval survival was low, with only 11% of hatching eggs reaching adulthood. In total, 20 adults were reared from 250 eggs. Larval development was retarded, particularly in the later instars, and developmental time ranged from 25 to 52 days (mean 36 days), compared with a normal time of 27 days for outbred larvae. When the progeny of these crosses were mated ( $F_{\text{offspring}} = 0.25$ ), hatching rates of eggs ranged from 42 to 59% (mean = 51%). Larvae hatching all contracted a probable viral infection in the fourth instar and died but this may not have been a direct effect of inbreeding.

3. *Other species*: In other papilionids, inbreeding depression as expressed by hatching rates of eggs from F1 sib-sib matings ( $F_{\text{offspring}} = 0.25$ ) was most severe in *Papilio aegeus* (Hatching rate 70%). Survivorship of hatching larvae was low (32%). Neither hatching rates nor larval survival rates in *Graphium macleayanum* and *Chilasa anactus* were significantly different from outbred matings. Similarly, by the same criteria, there was no evidence of inbreeding depression in either *Delias nigrina* or *Danaus affinis* (Table 1). In no cases were there any significant differences in size between parents and inbred offspring.

4. *Tellervo zoilus* (Fig. 6): There was no detectable reduction in hatching rates of eggs regardless of the degree of inbreeding ( $n=672$ ), and larvae experienced high survivorship ( $n=134$ ). However, adults with an inbreeding coefficient 0.5 and above characteristically were 10-20%

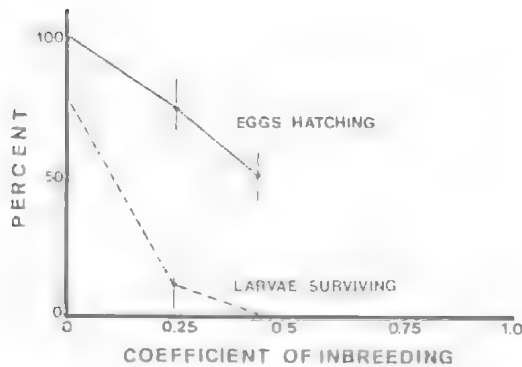


FIG. 4. Effects of increasing levels of inbreeding on hatching rates of eggs (solid line), and survival of hatching larvae (dashed line) in *Ornithoptera richmondia*. Vertical bars indicate standard deviations.

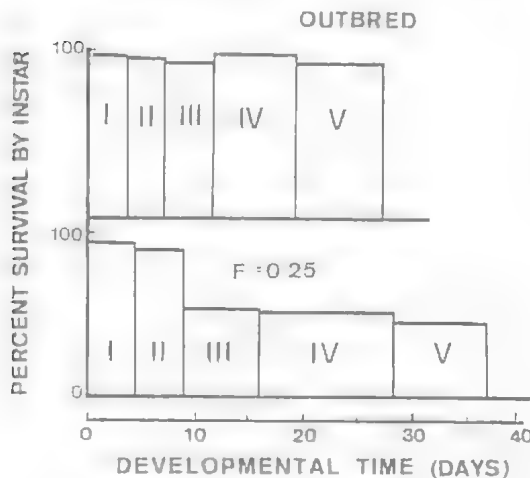


FIG. 5. Larval survival and rate of development by instar in inbred ( $F=0.25$ ) and outbred *Ornithoptera richmondia*.

smaller (based on forewing length) than the original wild stock, ( $n_{\text{inbred}} = 24$ ,  $n_{\text{outbred}} = 40$   $t=3.8$ ,  $p<0.001$ ). Corresponding with this, fecundity of females also dropped. There are no data on the normal relationship between fecundity and winglength but the fall in fecundity was of an order which suggested that no additional effects beyond the reduction in size were in operation.

**5. Inbreeding in nature:** For all species showing severe inbreeding depression in the ovum, large numbers of eggs were collected from wild females. In almost all cases, the natural hatching rate was close to 100%. However, in February 1987, three out of eleven wild female *O. richmondia* laid eggs with hatching rates ranging from

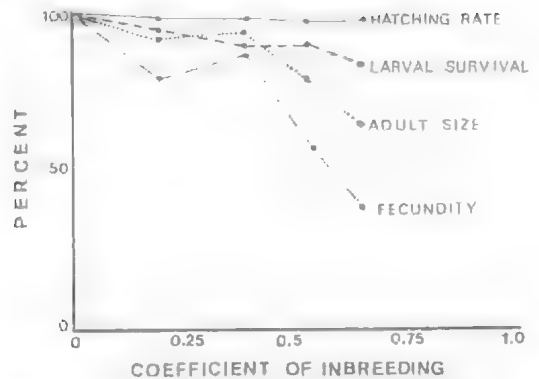


FIG. 6. Effects of increasing levels of inbreeding on hatching rate of eggs, larval survivorship, size and fecundity in *Tellervo zoilus*. Figures expressed as a percentage of outbred values.

64-76%. Hatching rates of eggs laid by the other eight individuals were normal (96-100%) and it seems most likely that low egg viability was a result of inbreeding as the individuals concerned were relatively young with fat body in good condition, as was determined by dissecting them after they had laid 50 eggs.

## DISCUSSION

Although inbreeding depression has been reported in captive populations of various Lepidoptera (Norris, 1936; Waldbauer & Sternberg, 1978), effects as severe as those reported here have never previously been recorded in butterflies even though extensive breeding experiments have been conducted on several papilionid species (Clarke, 1972; Lederhouse & Schriber, 1984). Whether inbreeding depression was low in those species or not revealed by the breeding programme or was simply overlooked or ignored is not clear. In the only study of an endangered species which has addressed the possibility of inbreeding depression, Dempster & Hall (1980) found no evidence of reduced egg viability in the wild even though they were studying a small and dwindling population.

By contrast, this study indicates that in three species examined, inbreeding depression is potentially severe. Notably, these three are all papilionids, probably with very open population structures, as determined by MRR programmes (Orr, 1988). Inbreeding depression was not detected in *Graphium macleayanum* or *Danaus affinis*, in which dispersal is more limited. However, there is no clear pattern or susceptibility,

since in neither was there evidence of strong inbreeding depression in *Chilusa anactus* or *Delias nigrina*, both of which probably have fairly open population structures. However, as the continued inbreeding of *Tellervo zoilus* shows, most species will suffer deleterious effects if the inbreeding coefficient is sufficiently high.

Although these results cannot validly be extrapolated to other species, they suggest that certain papilionid groups, especially Troidini, may be highly susceptible to inbreeding. The IUCN Red Data Book on Papilionidae (Collins & Morris, 1985) lists 4 species as endangered, 23 species as vulnerable and 59 species as indeterminate, rare or requiring further monitoring. These include some of the most spectacular and distinctive species. With 24% of the world fauna (including *O. richmondia*) on the list, troidines are particularly well represented. If levels of inbreeding depression recorded in *C. cressida* or *O. richmondia* were in any way typical of the tribe then the actual risk to these listed species is probably even greater than assessed. In particular, captive breeding programmes (see New, 1991), frequently suggested as part of a species conservation strategy, may be doomed (see Martin, 1975; May, 1980).

Any conservation programme must ultimately aim at preserving a self-sustaining gene pool, which in turn must lead to the protection of minimum areas of habitat. As part of the general programme to conserve papilionid butterflies in particular, and probably all butterflies, the degree of susceptibility to inbreeding of all species under consideration must be assessed. Species which have formerly been widely distributed and whose habitat has been reduced and fragmented may be most at risk. Particularly if they are unwilling to fly across unfavourable habitat, but all species are potentially at risk if their population levels diminish to low levels for many generations (Frankel & Soule, 1981).

#### ACKNOWLEDGEMENTS

I would like to express my appreciation to my parents, Mr and Mrs G.H. Orr, for their assistance in maintaining the insectary and for help in feeding hundreds of caterpillars. This work was supported partly by a Griffith University research grant and by a UBD conference grant.

#### LITERATURE CITED

- CLARKE, C.A. & SHEPPARD, P.M. 1962. Offspring from double matings in swallowtail butterflies. *Entomologist* (London) 95: 199-203.
- CLAYTON, G.A., KNIGHT, G.R., MORRIS, J.A. & ROBERTSON, A. 1957. An experimental check on quantitative genetic theory: III. Correlated responses. *Journal of Genetics* 55: 171-80.
- COLLINS, M.N. & MORRIS, M.G. 1985. Threatened Swallowtail Butterflies of the World - The IUCN Red Data Book. (IUCN: Gland, Switzerland and Cambridge, UK).
- DEMPSTER, J.P. & HALL, M.L. 1980. An attempt at re-establishing the swallowtail butterfly at Wick-en Fen. *Ecological Entomology* 5: 327-334.
- EHRLICH, P.R. 1965. The population biology of the butterfly *Ephedryas editha*. II. The structure of the Jasper Ridge colony. *Evolution* 19: 327-336.
1983. Genetics and the Extinction of Butterfly Populations. In Schonewald-Cox, C.M., Chambers, S.M., MacBryde B. & Thomas W. (eds). 'Genetics and Conservation: A reference for managing wild animal and plant populations'. (Benjamin/Cummings: Menlo Park, California).
- EHRLICH, P.R., BREEDLOVE, D.E. BRUSSARD, P.F. & SHARP, M.A. 1972. Weather and the regulation of subalpine populations. *Ecology* 53: 243-247.
- EHRLICH, P.R., MURPHY, D.D., SINGER, M.C., SHERWOOD, C.B., WHITE, R.R., & BROWN, I.L. 1980. Extinction, reduction, stability, and increase: the responses of checkerspot butterfly populations to the California drought. *Oecologia* 46: 101-105.
- FALCONER, D.S. 1981. 'Introduction to Quantitative Genetics'. 2nd Ed. (Longman: London & New York).
- FRANKEL, O.H. & SOULE, M.E. 1981. 'Conservation and Evolution'. (Cambridge University Press: Cambridge).
- GILBERT, L.E. & SINGER, M.C. 1973. Dispersal and gene-flow in a butterfly species. *American Naturalist* 107: 58-72.
- GREENWOOD, P.J. & HARVEY, P.H. 1978. Inbreeding and dispersal in the great tit. *Nature* 27: 52-54.
- LEDERHOUSE, R.C. & SCHRIBER, J.M. 1984. Ecological significance of a postmating decline in egg viability in the tiger swallowtail. *Journal of Lepidopterist's Society* 41: 83-93.
- MARTIN, R.D. (ed). 1975. 'Breeding Endangered Species in Captivity'. (Academic Press: London).
- MAY, R.M. 1980. Inbreeding among zoo animals. *Nature* 283: 430-431.
- NEW, T.R. 1991. 'Butterfly conservation'. (Oxford University Press: Melbourne).
- NORRIS, M.J. 1936. Inbreeding in *Ephestia kuhniella* Z. (Lepidoptera: Phycitidae). *Journal of Genetics* 32: 179-181.

- ORR, A.G. 1988. Mate conflict and the evolution of the *sphragis* in butterflies. (PhD Thesis, Griffith University: Brisbane.)
- WALDBAUER, G.P. & STERNBERG, J.G. 1978. Inbreeding depression and a behavioral mechanism for its avoidance in *Hyalophora cecropia*. American Midland Naturalist 102: 204-208.
- WALLACE, B. & MADDEN, C. 1965. Studies on inbred strains of *Drosophila melanogaster*. American Naturalist 99: 495-509.
- WOLDA, H. 1978. Fluctuations in abundance of tropical insects. American Naturalist 112: 1017-1045.
- WRIGHT, S. 1977. Inbreeding in animals: differentiation and depression. Pp. 44-96. In 'Evolution and the Genetics of Populations', Vol. 3. (University of Chicago Press: Chicago, Illinois).

## STORIES WE TELL ABOUT FAUNA

KRISTINE P. PLOWMAN

Plowman, K.P. 1994 06 30: Stories we tell about fauna. *Memoirs of the Queensland Museum* 36(1): 185-190. Brisbane. ISSN 0079-8835.

I explore the connections between the continuing reduction of biodiversity and the stories we tell about fauna. The majority of these stories are strongly scientific in content and form, usually emphasising rationality and the control and exploitation of nature. Some stories may also function to preserve cultural boundaries. Very few are poetical and imaginative in form. Consequently, I argue that — in conjunction with the highly urbanized life styles in Australia — most people see the stories as outside their culture. Not only are the stories 'outside', so are the animals. Unless most Australians, particularly public administrators and politicians, gain empathy with the non-human world, the processes of public administration and forward planning will be ineffectual — if not detrimental — for a safe future for our biodiversity. As scientists, we can help by telling different stories. □ *Biodiversity, conservation, invertebrates, vertebrates, communication, culture, stories, ethics, morality, science, folk*.

Kristine P. Plowman, *Environmental Research and Education*, PO Box 363, Red Hill, Queensland 4059, Australia; 3 August 1993.

At this conference we are discussing invertebrate biodiversity and there is one fact of which we are all aware: the biodiversity of the world is under siege. It is under siege as forests are felled, as urbanisation continues across the landscape, and as land and water are polluted and degraded. The non-human (which is usually called natural — but in what way are we unnatural?) world is being colonised by humans and their artefacts, with an ensuing loss of ecosystems, habitats and species.

Yet, despite this destruction, the human behaviours that cause it do not seem to be changing and many of us often ask each other, 'What can be done to halt this great loss, this extinction of species and of spirit?' I suggest we need to look at our behaviour as scientists. And we have some changing to do. I argue that we need to think about, speak about and interact with the non-human part of our world in different ways.

To understand how this might be done, we need to explore what is it that scientists are saying to people about this world we live in. And one way to do this is to explore the stories<sup>1</sup> we tell about the non-human world, specifically the fauna.

Such an exploration is heuristic. We can learn for ourselves about ourselves: we can come to appreciate the special ways we use symbols and

how these influence our own behaviours and that of others. Humans have always used metaphors, including ones involving animals, to explain and rationalise themselves to themselves — and scientists are no different. I contend, that in our stories about fauna, we can discover the detrimental aspects of our behaviour and change them. We can change them by fashioning different ways of speaking about, and relating to, the non-human world and ourselves. This will entail telling different stories with different explanations.

Culturally, through different explanations, we may be more able to appreciate and respect animals other than ourselves. It is worth the try. If we modify our explanations of the world, if we explain ourselves to ourselves differently, perhaps we will also modify our adverse interactions with, and impacts upon, the world in which we live.

### ANIMAL STORIES A PERSONAL REFLECTION

What stories do we tell about our fauna? and what stories about our fauna are important for people living in our culture? I first began to explore these question when I started to give

<sup>1</sup>I argue that humans have always told stories to themselves to explain the world and their human condition. Some would regard the use of the term 'story' as one that trivialise these explanations. I do not use the term in a trivial sense. Others argue that there are explanations that either true and or not. I regard all these as stories. Every story in its way provides us with a further explanation of ourselves.

public talks and lead outings some years ago. The answers were important for successfully performing these tasks.

(More recently, I have wondered about the same questions because of the lack of response from the community in general, and administrators in particular, to the promotion and conservation of biodiversity. Here the answers were important for understanding failure).

When I tell a story about this animal or that, what do people actually hear? What does it mean to them? The audiences I most often address comprise middle class parents and children who live in urban landscapes. Notably, with these audiences, activities based on natural history and bush experiences are considered suitable and important for children although it has not ever been clear to me whether or not the activities are considered suitable or important for adults.

The stories I tell are the stories that were told to me by my family and my teachers, mostly the latter. There was the story my grandfather told me of the hoop snake, which rolls itself into a hoop and attains frightening speeds as it rushes down hills; and the poems my mother read to me about the mythical Bunyip. Take, for example, this description (Stewart, 1973) of the beast and its habitat:

The water down the rocky wall  
Lies fall its shining stair;  
The bunyip in the deep green pool  
Looks up it to the air.  
The kookaburra drank, he says, then shrieked at me with laughter,  
I dragged him down in a hairy hand and ate his thighbones after;  
My head is bruised with falling foam, the water blinds my eye  
Yet I will climb that water fall and walk upon the sky.

The turpentine and stringybark,  
The dark red bloodwoods lean  
And drop their shadows in the pool  
With blue sky in between.

A beast am I, the bunyip says, my voice a drowning cow's.  
Yet am I not a singing bird amongst these waving boughs?  
I raise my black and dripping head, I cry a bubbling cry,  
For I shall climb the trunks of trees to walk upon the sky.

Gold and red the gum trees glow,  
Yellow gleam the ferns;  
The bunyip in the crimson pool  
Believes the water turns.

I know the roots of rocks, he says, I know the door of hell;  
I ate the blackman's daughter once, I know my faults full well;  
Yet sunset walks between the trees and sucks the water dry,  
And when the whole world's burnt away I'll walk upon the sky.

The little frogs they call like bells,  
The bunyip swims alone;  
Across the pool the stars are laid  
Like stone by silvery stone.

What did I do before I was born, the bunyip asks the night;  
I looked at myself in the water's glass and nearly died of fright;  
Condemned to haunt a pool in the bush while a thousand years go  
by—  
Yet I walk on the stars like stepping stones and I'll climb them into  
the sky.

A lady walks across the night  
And sees a mirror there;  
Oh, is it for herself alone  
The moon lets down her hair?

The yabbie's back is green for her, his claws are opal-blue,  
Look for my soul, the bunyip says, for it was a jewel too.  
I bellowed with woe to the yabbie once, but all I said was a lie,  
For I'll catch the moon by her silver hair and dance her around the  
sky.

## A STUDENT'S PERSPECTIVE

Most of the stories I learnt, however, were as a student. I learnt about the cockroach, the shark and the toad in studies of vertebrates. The emphasis was on the evolutionary history of vertebrates with little attention to Australian fauna. In fact little was known about the Australian native vertebrate fauna at that time. Studies of invertebrates included more examples of Australian animals, as well as field trips to the sea shore. The invertebrate stories I learnt were those found in such text books as *Animals without backbones* (Buchsbaum, 1951). And Barnes (1980: 1-7):

There are over a million described species of animals. Of this number 5% possess a backbone and are known as vertebrates. All other comprising the greater part of the Animal Kingdom are invertebrates.

Division of the Animal Kingdom into vertebrates and invertebrates is artificial and reflects a historical human bias in favour of man's own relatives. One characteristic of a whole sub-phylum of animals is used as the basis for the separation of the entire Animal Kingdom into two groups. One could just as logically divide the entire animal kingdom into mollusks and non-mollusks or arthropods and non-arthropods. The latter classification could be supported at least from the standpoint of numbers, since approximately 85 per cent of all animals are arthropods....

The Animal kingdom is generally believed to have originated in Archaeozoic oceans long before the first fossil record. Every major phylum of animals has at least some marine representatives....

In subsequent chapters the evolutionary histories of the various phyla are explored. Their evolutionary history is frequently used as a

basis for understanding the adaptive diversity within the phylum or class.

Thus, the first animal stories I learnt were overwhelming the animal stories of science — of Linnean classification. And of structure, function, adaptation, reproductive strategies, and relationships. The context in which these stories were embedded was usually an evolutionary one. It was only towards the end of my undergraduate training that I learnt about another context — the ecological one. At university I did not learn any stories about alternative systems of classification (although I learnt of these later when I lived in different cultures: Dwyer & Plowman, 1981). Sometimes, I did learn stories about animals that were dangerous to man, useful to man and some that were eaten by man. But even this information was not often proffered.

### ANIMAL STORIES I HAVE TOLD

These were the stories I usually told when I gave public talks. Occasionally I experimented. I asked the audience questions such as, 'What do you think of when you hear the word kangaroo or koala?' — an exploration in symbols. Sometimes I spoke about the natural history of an animal. For example, flying foxes. I talked about their ways and I took flying foxes to talks and showed people them. I would ask people to hold one. 'Overcome your resistance and feel this animal: feel, listen and smell', I said. And sometimes I read a poem that seemed to me to be particularly evocative of Brisbane.

And it was evocative and potentially disruptive. So much so, now I rarely read out the poem (Shapcott, 1969). It is outside the bounds of empiricism and into subjective associations: another animal and the self. Yet it is a story many know.

She tosses and rumples alone on the double bed:  
when, damn him, when will his car cringe in  
through their gate and clatter over the one loose  
stone  
to announce his coming? Her life has become a  
code  
of sound, a mesh of reassurances  
and locks. She wills herself still and tight. No use,  
each minute drums with the wrong silence, the  
wrong noise  
on the rigid tendons of her own unease.

And still she waits, as tensely as she listens, and hears  
in the rank-growing neighbour pawpaw-tree outside  
a marauding flying-fox circle and flap and eling

scooping the ripe air, gripping with clawed wings  
at its easy quarry, the fleshy neglected fruit,  
and tear through its shallow skin, and feast on it.

And what were stories I told that aroused the most interest? There was the story of *Antechinus*, the marsupial mouse, where the males, in one season, mated then died in a collapse of all their bodily functions. The females go on to rear their young alone (Plowman, 1987). Another story of interest was of species of *Collembola* in which males and females lead separate lives not even meeting for reproduction. Sex is the male depositing sperm packets for the female to chance upon. When the female finds a sperm package she first evaluates it. If fresh, she collects the package to fertilise her eggs, if not — she eats it (CSIRO, 1991). Another story that generated interest was concerned with butterflies that drank the tears of cows and turtles (Hand, 1991).

### ANIMAL STORIES AND POPULAR CULTURE

What other stories are there about animals in the public domain? I decided to spend a morning researching this question in my local Bookworld store. Here I found many books that I would class as natural history publications. Books about the landscape of Australia, the plants and animals. On the morning I undertook the survey there were well over one hundred books that fitted this category. Of these, about 27 were concerned with animals, 'including birds and reptiles' as one cover said.

'Including birds and reptiles' illustrates how animals are seen in the popular market place: they are usually mammals — the warm and cuddlies (Van Dyck, 1991). And what did my text book (Barnes, 1980) say? — 'One characteristic of a whole sub-phylum of animals is used as the basis for the separation of the entire Animal Kingdom into two groups.'

Most of the animal books were concerned with vertebrates, particularly mammals, and a few were concerned with both vertebrates and invertebrates. Of invertebrate books, the ones that made it onto the shelves were in the main: insects (mostly butterflies and to a lesser extent beetles), arachnids (mostly spiders) and some of the coelenterates. That is, the beautiful and the dangerous. There was only one book about insect pests of vegetables and one book about 'Insects...' and in much smaller print 'other



invertebrates'.

Basically 95 per cent of the fauna is invisible in Bookworld. If it is invertebrate and visible it is generally symbolic of either beauty and renewal, or death and dissolution. These are old themes which run through our western cultural tradition. Czechura (1994) noted similar themes in his analysis of public enquiries received at a museum.

And what did these books discuss? Let me briefly talk about two. *The living world of animals* (Readers Digest, 1971) discussed, according to the preface, animals in their natural surroundings and the past, the present and the future of animal life. The emphasis was on the orthodox scientific view of animal life. I turned to two chapters: one headed 'Man's place in the animal world', the other 'Animals in human culture'. Both chapters covered only two pages with illustrations taking up about half of the space. This is an extract of what I found (p. 357):

Man's relationship with other species covers a wide range; he competes with many for food and living space; he exploits and preys on some; he dominates others by selectively breeding them, and he is host to parasites on or in his body.

It goes on to say

...that man has changed much of the natural habitats with agriculture and urbanisation but while some animals have been lost, others have benefited from these man made modifications.

Many other animals help man... Even flies...help by breaking down dead organisms and bees pollinate flowers.

(I thought that this was happening well before man made his first wobbly steps into the African savanna).

Man also has animal enemies and competitors for food.

Some animals compete with man by attacking his food supplies and property...No animal species relies entirely on man.

And in 'Animals in human culture' (p. 364):

Man's dependence on his fellow animals has always been coloured by such emotions as fear, reverence and curiosity and these have often found expression in art and literature.

These expressions have been recorded in cave paintings and totemism.

As civilisation developed, gods became less like animals and more like men. Just as often animals were represented as the dark side of creation.'

My response to this book was a picture of man (and 'man' expressively as the masculine) taking the centre stage with the other animals as lesser parts of his domain. Man the controller. And, as man becomes more 'civilised', the more dis-

tanced he becomes from his animal origins. This reflects another powerful story embedded in western culture and philosophy, that is the notion of dualism: culture/nature, spirit/body, male/female, good/evil.

The book also took the contribution of science as given, as though it was natural and had nothing to do with culture. This is a misleading story. Science is after all only a method of investigation — a powerful method, but still an invention of men to explain the world. Freud (1951) wrote that there were three major explanations of the world: animism, religion and science. On the contribution of science to the way we see animals and to the way we explain the world, *The living world of animals* makes no mention.

The second popular book was *Australia's dangerous animals* (Readers Digest, 1987). In the introduction, it states that:

No kind of creature possesses a greater or more constant threat to human well being than ourselves...animals have power over us and offend our notion of mastery. Injuries, envenomations and infections from supposedly inferior beings excite resentment and even hatred. Such emotions often mask a primitive fear — our inheritance from ancient man's struggle to survive in a world inhabited by many more dangerous creatures than exist today.

After this warning, this publication goes on to excite readers with stories of ants as hazards in hospitals, where the immobile and helpless are slowly carted away by seething ants attracted to their bodily fluids. It then amuses with the story of two English sisters paddling knee deep in the Mediterranean when one was grabbed by an octopus (tentacles about 75cm in length). Her sister went to her aid and helped release her from the molluscs grasp. Subsequently, the sisters watched the story grow in the media. After some time the tentacles became 12m in length. The story of the octopus was eventually glossed to carry away two beautiful, young, American women to their death.

The book had other stories. Stories of fear — fear of death perhaps — where dissolution and the destruction are illustrated with tales of the effects of spider and snake venoms.

## SOME OTHER ANIMAL STORIES

As well as these type of stories, there are other animal ones from our culture that are stories concerned with morality and 'proper' conduct. For example, there are stories of ants as role

models such as, 'Go to the ant thou sluggard'. There are sociobiological stories based on animal behaviour, and apparently legitimised by science, about how men and women should conduct themselves in human society (e.g. Wilson, 1975; Gould, 1977; Tiger, 1984).

There are other stories about brutal and bestial animal desires. Mary Midgley (1978) used wolves as an example of how particular animals have a 'folk figure that has been popular with philosophers'. She goes on to say (p. 27):

I once read a chatty journalistic book on wolves, which described in detail how wolves trapped in medieval France used to be flayed alive, with various appalling refinements. "Perhaps this was rather cruel" the author remarked, "but then the wolf is itself a cruel beast" The words sound natural, it is quite difficult to ask oneself: do wolves in fact flay people alive? Or to take in the fact that the only animal that does this sort of thing is *Homo sapiens*. Another complaint the author made against wolves was their treachery. They would creep up on people secretly, he said and then attack so suddenly that their victims did not have time to defend themselves. The idea that wolves would starve if they gave fair warning never struck him. Wolves in fact, have traditionally been blamed for being carnivores, which is doubly surprising since most people who blamed them normally eat meat themselves....

People hide their dark sides in the supposed natures of other animals.

### CONCLUSION

We tell a number of types of stories about animals and these stories serve different functions. In western culture, generally, some of the stories are about maintaining boundaries, boundaries concerned with dissolution and death, or social boundaries concerned with control and order. Others are stories of our control over nature where animals are symbols of nature — raw and brutal — and we humans are representative of civilisation and the highest spiritual realm.

There are stories that rationalise the past inequalities between men and women and cruelties to other human groups and other animals. There are stories that recognise only objective, rational knowledge and the control of natural forces. And stories that deny our dark and fearful selves in the motives and action of other animals. These stories reflect a complex of human responses (most of which are probably quite ancient) to, and explanations of, the world or worlds in which we live or have lived as a species.

In Australia we predominantly tell animal

stories that are scientific stories. And, generally, these encapsulate notions of control and progress through evolution and empiricism, with an emphasis on content rather than poetical form. Also, science, itself, wears a belief that it is outside culture — another story.

This mix of stories is a recipe of alienation. It distances us from other life forms. As most Australians already live in a domesticated, urbanised world dominated by human artefacts, the mix enhances our sense of separateness and distance from the non-human.

If we are to promote a notion of the importance of species diversity, of a world rich in organic expression, then I suggest we need to fashion different stories about ourselves and the non-human world. Stories that are not about dualism, distance and domination: stories where our connection with the earth is important — important both pragmatically and spiritually.

We need to live as though our Father's mansions are on earth rather than elsewhere in time and space. We need to care for ourselves and for the earth with respect. These are not new ideas. Many people have suggested similar reactions to the constraints in our western culture (e.g. Martin, 1982).

These changes in scientific culture are not easy to achieve. Moreover, even if we do achieve them, we still might be going nowhere.

We do not act alone. The community in general — and public administrators and politicians in particular — also have to change. They, too, have to acknowledge the importance of the non-human world and integrate this respect into their own lives and endeavours. They, too, have to eschew behaviours that seek to control or exploit nature or radically refashion it. If they are not with us, biodiversity will continue to be destroyed with terrible losses of ecosystems and plant and animal species.

We are influential. As scientists, we can look carefully at the stories we tell, the language we use, and facilitate change, at least in part, by telling stories that celebrate and respect life and generously and poetically include both facts and feelings.

Well I'll tell you about this story,  
about story where you feel...laying down.  
Tree, grass, star...  
because star and tree working with you.  
We got blood pressure  
but same thing.. spirit on your body,  
but e working with you.

Even nice wind e blow...having sleep...  
 because that spirit e with you.  
 Listen carefully this, you can hear me.  
 I'm telling you because earth just like mother  
 and father or brother of you. The tree same thing.  
 Your body, my body I suppose,  
 I'm same as you...anyone.  
 Tree working when you sleeping and dream.

Bill Neidjie (1989: 2-3).

#### ACKNOWLEDGEMENTS

I thank Margaret Somerville for her encouragement and comments on the MS, and Glen Ingram for his encouragement and for presenting this paper on my behalf to the conference.

#### LITERATURE CITED

- BARNES, R.D. 1980. 'Invertebrate zoology.' (W.B. Saunders Company: Philadelphia).
- BUCHSBAUM, R.M. 1951. 'Animals without backbones: An introduction to the invertebrates.' (Penguin: London).
- CSIRO 1991. 'The insects of Australia'. (Melbourne University Press: Australia).
- CZECHURA, G.V. 1994. Is the public really interested in invertebrates? What the Queensland Museum Reference Centre enquiries from 1986-1993 tell us. *Memoirs of the Queensland Museum* 36: 41-46.
- DWYER, P.D. & PLOWMAN, K.P. 1981. Edible internal parasites from Papua New Guinea. *Search* 12: 409.
- FREUD, S. 1951. 'Totem and taboo.' (Routledge and Kegan Paul: New York).
- GOULD, S.J. 1977. 'Ever since Darwin: Reflections in natural history.' (W.W. Norton: New York).
- HAND, S. 1991. A taste for tears. *Australian Natural History* 23(11): 826
- MARTIN, V. (ed.). 1982. 'Wilderness'. (Findhorn Press: Findhorn, Scotland).
- MIDGLEY, M. 1978. 'Beast and man: The roots of human nature.' (Cornell University Press: New York).
- NEIDJIE, B. 1989. 'Story about feeling.' (Keith Taylor, ed.) (Magabala Book: Broome).
- PLOWMAN, K. 1987. To die so young: another Australian mystery? *Wildlife Australia* 24(2): 22-25.
- READERS DIGEST 1971. 'The living world of animals.' (Readers Digest: Sydney).
1987. Australia's dangerous animals.' (Readers Digest: Sydney).
- SHAPCOTT, T. 1969. Flying-fox. P. 95. In 'Australian poetry, 1969.' (Angus and Robertson: Sydney).
- STEWART, D. 1973. The Bunyip. P.30. In 'Selected poems.' (Angus and Robertson: Sydney)
- TIGER, L. 1984. 'Men in groups.' 2nd ed. (Marion Boyers: New York).
- VAN DYCK, S.M. 1991. The status of mammals. Pp. 349-353. In Ingram, G.J. & Raven, R.J. (eds). 'An atlas of Queensland's frogs, reptiles, birds & mammals.' (Queensland Museum: Brisbane).
- WILSON, E.O. 1975. 'Sociobiology.' (Harvard University Press: Harvard).

## AUSTRALIAN FRESHWATER MOLLUSCA: CONSERVATION PRIORITIES AND INDICATOR SPECIES

W.F. PONDER

Ponder, W.F. 1994 06 30: Australian freshwater mollusca: conservation priorities and indicator species. *Memoirs of the Queensland Museum* 36(1): 191-196. Brisbane. ISSN 0079-8835.

Many Australian freshwater invertebrates are widespread but two types of freshwater systems have significant, locally endemic, invertebrate faunas: springs associated with the Great Artesian Basin, and long-term permanent streams in the coastal drainages of SE Australia and Tasmania. Hydrobiid gastropods are characteristic of these habitats and many species occupy very restricted distributions and thus are not amenable to a strictly habitat-based conservation strategy. Hydrobiids appear to be useful indicators of long-term permanent streams and might aid in the identification of areas where other freshwater invertebrates with poor dispersal powers have speciated. Much of the known diversity in hydrobiid snails is in areas afforded little or no protection. Changes to land management practices are required to ensure their survival. □ *Conservation, biodiversity, indicator species, freshwater, invertebrates, Mollusca, Hydrobiidae, Australia.*

W.F. Ponder, Invertebrate Division, Australian Museum, PO Box A285, Sydney South, N.S.W. 2000, Australia; 3 December 1993.

Although there have been more documented extinctions of non-marine molluscs than of mammals and birds combined (Groombridge, 1992), this circumstance has not been foremost in the conservation debate (Wells, 1986; Ponder, 1992). Of extinct molluscs listed, 22% are freshwater species, mostly from the USA. Freshwater molluscs, however, are severely threatened in many parts of the world. Clarke (1970) estimated that about half of the species in the USA was either close to extinction or extinct. The next edition of the *IUCN Red List* will include 285 extinct land and freshwater molluscs, compared with 191 in the 1990 edition.

Australia lacks the obvious, spectacular radiations of freshwater faunas seen, for example, in the Mekong River (Brandt, 1974; Davis, 1979), the Americas (Burch, 1975, 1982) and in some ancient lakes (Boss, 1978). So, is there a problem with the conservation of our freshwater molluscs? Non-marine molluscs are often vulnerable to habitat destruction or disturbance: many have very restricted distributions, for example, camaenid land snails (e.g. Solem, 1988). Similarly, some species of aquatic molluscs, especially hydrobiid snails, are very restricted — species are often found only in one spring or a few closely adjacent ones, notably in arid environments (e.g. in the Americas [Hershler, 1985; Hershler & Sada, 1987] and Australia [see below]). In hydrobiids, marked local genetic differentiation,

including speciation, can occur within discontinuous habitats a few kilometres in extent, even in areas of high rainfall such as at Wilsons Promontory in southern Australia (Ponder & Colgan, 1992; Colgan & Ponder, 1994).

Locally restricted species can undergo rapid extinction following habitat destruction (e.g. the land snail genus *Achatinella* in Hawaii [Hadfield, 1986; Solem, 1990]) or following the introduction of new predators (e.g. Clarke et al., 1984). In all, it is clear that highly restricted populations are generally more vulnerable than widespread taxa. Small streams and springs in SE Australia are under threat from activities including agriculture, forestry and damming. In many areas, there are hydrobiid species (and perhaps other aquatic invertebrates) that are very limited in distribution but are presently not recognised as restricted because they are undocumented and/or unnamed. During fieldwork, many situations have been observed where species are so restricted in their ranges that even a small, local development (e.g. farm dam) could have a serious impact or even contribute to the species' extinction.

### LOCALISED SPECIATION

Invertebrates with poor dispersal capabilities restricted to permanent, isolated aquatic habitats, sometimes speciate readily. In many parts of

Australia such permanent waters are uncommon but often contain unusual, endemic invertebrate faunas. Investigations on the most speciose group of freshwater snails (Hydrobiidae) revealed an unexpectedly large fauna of local endemics in south eastern Australia, Tasmania (Ponder et al., 1993), Lord Howe Island (Ponder, 1982) and in artesian springs in northern South Australia and western Queensland (see below). Many species are confined to very restricted habitats — for example, a single watershed, a few (or even single) springs or a single, small coastal creek. More than 90 Australian hydrobiid taxa will be included in the new edition of the *IUCN Red List*, none having been listed previously (IUCN Conservation Monitoring Centre, 1988), and many others are still unnamed.

It is almost impossible to make informed judgments about the taxonomy, speciation patterns and management of these localised populations without data on population genetics (see Daniell, 1994). Consequently a program was commenced with Dr D. J. Colgan, to investigate the basic genetic structure of hydrobiid populations in three locations with different habitat types: Wilsons Promontory (Victoria) and the artesian springs of Lake Eyre (South Australia) and Dalhousie (see Colgan & Ponder, 1994). The latter two spring systems exhibit very different historical, limnological and topographic characteristics.

Among 75 Wilsons Promontory hydrobiid populations examined, four genetically distinct, sympatric species in an area only 15km in maximum extent were identified using allozyme electrophoresis (Ponder et al., 1994b; Colgan & Ponder, 1994). With one exception, these species were morphologically indistinguishable. Observations based on morphology alone indicate that considerable speciation has occurred in other areas of SE Australia and Tasmania (Ponder et al., 1993) and the discovery of many cryptic species is likely using genetic techniques.

There is evidence that extinctions (probably many) have occurred throughout SE Australia, primarily due to land clearing for agriculture and towns. However, in areas where even small patches of original vegetation have been maintained around water sources, faunas have often persisted — an indication that there is some hope of long term survival with minimal management.

#### INDICATOR SPECIES IDENTIFYING AREAS OF ENDEMISM

Many of Australia's lakes and rivers dried

during aridity induced by the last glaciation. De Deckker (1986) argued the Australian aquatic fauna was adapted to an environment requiring good dispersal mechanisms. Some long-term water bodies such as artesian springs, however, provided refuges for animals with poor dispersal capability and no effective desiccation-resistant stage in their life cycles. It follows that such animals can be used to identify the water bodies that contained permanent water throughout much of the Pleistocene and Holocene.

Australian freshwater invertebrates that are poor dispersers and lack the ability to withstand even short term desiccation at any stage of their life cycle include some flatworms, amphipod and isopod crustaceans and hydrobiids. Such animals tend to be (with some exceptions) associated with long-term permanent aquatic habitats and could be used as indicators of such habitats. Because such habitats have been in existence for long periods of time, and because they are often isolated from one another, they are much more likely to contain endemic species than more ephemeral bodies of water.

#### CONSERVATION OF INVERTEBRATES WITH LIMITED RANGES

Discussion on conservation of Australia's aquatic fauna has largely focused on vertebrates (e.g. Michaelis, 1986). Although many invertebrates will be incidentally catered for in the reserves created with other conservation aims (e.g. scenery, trees or vertebrates), additional measures are required for invertebrate conservation (Wells, 1986; Solem, 1990; Yen & Butcher, 1992). Small patches of forest can provide important habitats for molluscs and other biota (e.g. Bouchet, 1990; Meave et al., 1991), including small vertebrates such as frogs, although generally inadequate for larger vertebrates. Such habitats do not have to be formal reserves. A change in land care culture would make a big difference if remnant forested gullies, for example, are treated as an asset. Maintenance of stream-side vegetation not only helps protect aquatic and terrestrial habitats but maintains water quality and prevents erosion.

Resource utilization by humans is a common cause of habitat destruction and the conflicts arising from such use are major impediments in land conservation. I will now briefly outline examples from two very different freshwater ecosystems to illustrate the fragility of these environments and problems arising from utiliza-

tion of their resources.

### SPRINGS OF THE GREAT ARTESIAN BASIN

Access to artesian water is considered a fundamental right for anyone utilizing arid lands in Australia. However, artesian water is also essential to the continued existence of more than 40 species of aquatic invertebrates that live in unusual and biologically unique natural springs.

Artesian springs in arid areas around the world contain relictual and endemic biota (Cole, 1968). The Great Artesian Basin (GAB) — 22% of the area of Australia — has numerous artesian springs on its fringes (see overviews by Ponder, 1986; Zeidler & Ponder, 1989; Boyd, 1990) and are the only natural sources of permanent water in this mainly arid area. While the South Australian springs have gained some attention from conservationists (see Harris, 1981, 1993), other important springs in western Queensland (Ponder, 1986; Ponder & Clark, 1990) have been largely ignored. Many of the GAB springs — often called 'mound springs' — contain rare flora, endemic fishes and invertebrates (Mitchell, 1985; Ponder, 1985, 1986). Many of them, however, have ceased to flow in the last one hundred years because of water extraction from the Basin, and most of the remaining springs are under threat. Only one spring group in South Australia and one very minor group in Queensland are protected. The remainder are on pastoral land.

The hydrobiid snails are the most speciose invertebrates of GAB springs with three separate radiations in mainly endemic genera. Two are in South Australia: one near Lake Eyre (two genera) (Ponder et al., 1989), the other in Dalhousie Springs (Ponder, 1989); and a third is in western Queensland (Ponder, 1986; Ponder & Clark, 1990). Other interesting, relict endemic invertebrates include a macrostomid flatworm and ostracod, isopod and amphipod crustaceans (see Ponder, 1986 for summary). The endemic genera, even subfamilies, in some groups of artesian springs suggest that they are relicts of a now mostly extinct, early Pleistocene or late Tertiary inland freshwater fauna (Ponder, 1986; De Deckker, 1986) or possibly an older fauna associated with artesian springs of the Tertiary.

Biological information, including data on population genetics, is needed to provide a basis for management. Even though these small springs are often widely separated by arid countryside, preliminary studies on the genetic structure of

hydrobiid populations have shown that the levels of gene flow between springs are actually higher than between small streams on Wilsons Promontory in moist, temperate south eastern Victoria (Colgan & Ponder, 1994). This might be largely due to differences in the accessibility of these habitats to birds, which act as primary dispersal agents (Ponder et al., 1994b).

The heavy usage of artesian water over the last hundred years has caused the extinction of many springs (Ponder, 1986) and, with them, their aquatic biota. Nearly all artesian springs in NW New South Wales are now dry as are many in Queensland, particularly in the western, northern and southern parts of the basin. In some areas, the few remaining springs are so reduced in flow they are highly vulnerable to stock damage. Consequently, the extinctions of the fauna they contain appear to be inevitable.

Legislated protection of all spring groups known to contain endemic faunas is essential and overdue. This action, however, must also be coupled with proper management and conservation of artesian water if the springs are to continue to exist and their endemic biota survive.

### WESTERN TASMANIA

One might assume that a very wet area provides an environment conducive to the dispersal of freshwater invertebrates. This is not necessarily a correct conclusion. In the larger rivers of western Tasmania, up to 80-90 macroinvertebrate taxa can be expected in the riffle zones (Richardson & Swain, 1978) — and this figure is similar to those found in rivers in Victoria and in other parts of Tasmania. Some invertebrate groups (summary in Ponder et al., 1994a), such as insects, crustaceans and molluscs are well known and also show high levels of endemism (Williams, 1974; Campbell, 1981; Ponder et al., 1994a).

Aquatic molluscs have generally been regarded as a minor, uncommon component of the fauna (e.g. Malcolm, 1987; Chilcott, 1987). Recent studies, however, show that many species of snails of the world-wide Hydrobiidae are found in Tasmanian lotic systems and, occasionally they are locally very abundant (e.g. Coleman, 1978). Many, perhaps unexpectedly, have restricted distributions (Ponder et al., 1993) and some species are apparently restricted to single streams or springs.

Species in most other Tasmanian freshwater mollusc families also have wide distributions



(Smith & Kershaw, 1981) but there are a few exceptions. These include an unnamed lymnaeid gastropod so far found only in the lower section of the Franklin River. (Had it not been for the successful campaign to prevent the damming of the Franklin River this species — and several locally restricted hydrobiids — would now undoubtedly be extinct). The large limpet-like planorbid, *Ancylastrum*, is listed as endangered (Michaelis, 1986) and occurs in a few lakes in central Tasmania where it is severely threatened by hydro-electric developments and predation by trout.

While a significant proportion of western Tasmania falls within the World Heritage Area, very diverse faunas are also found in the mainly unprotected northwest and north coast drainages. Even within protected areas, exotic fishes that feed on native fishes and invertebrates can become established and almost impossible to control. This also applies to exotic competitors such as the introduced hydrobiid *Potamopyrgus antipodiarum* (Ponder, 1988).

The damming of rivers or clear-felling of forests has dramatic effects on localised invertebrates by destroying or markedly altering habitats in catchments. Downstream impacts on invertebrates from developments such as dams (e.g. King & Tyler, 1982 for the Gordon River below Gordon Dam) or mines (e.g. in the King River, Lake et al. [1977] and Swain & White [1985]) can also be considerable.

Lotic habitats in the main are more likely to contain endemic species because of the recent origin of most lakes. The destruction of Lake Pedder in 1972 by hydro-electric 'development' rightly caused anguish but, in all probability, the now drowned streams previously feeding the lake contained more animals that were unique. However, in spite of the high profile of the controversies about dams, other activities such as forestry, and particularly agriculture, continue to have the greatest destructive impact on freshwater biota.

Michaelis (1986) and others have stressed the need for habitat conservation, rather than the individual species approach. Whereas habitat conservation is very important, if our aim is to conserve maximum diversity, the identification of significant areas of endemism must also be pursued. Such areas exist through a combination of local physical and historical factors and can be overlooked by using a strictly habitat-based approach.

## ACKNOWLEDGEMENTS

This work has been funded by grants from ARC, ABRS, and the Endangered Species Program. I thank W. Zeidler, D. Colgan, G. Clark, A. Miller, J. Waterhouse, A. Toluzzi, P. Egger and T. Terzis for their help with the various projects briefly summarised in this paper and Dr. P. Bouchet and Dr. D. Bickel for comments on the manuscript.

## LITERATURE CITED

- BOSS, K.J. 1978. On the evolution of gastropods in ancient lakes. Pp. 385-428. In Fretter, V. & Peake, J. (eds), 'Pulmonates. Volume 2A. Systematics, evolution and ecology'. (Academic Press: London).
- BOUCHET, P. 1990. Extinction et conservation des espèces dans le monde tropical: quel avenir pour les Mollusques? *Cahiers d'Outre-Mer* 42: 475-488.
- BOYD, W.E. 1990. Mound springs. Pp. 107-108. In Tyler, M. J., Twidale, M., Davies, M. & Wells, C. B. (eds), 'Natural history of the north east deserts'. (Royal Society of South Australia: Adelaide).
- BRANDT, R.A.M. 1974. The non-marine aquatic Mollusca of Thailand. *Archiv für Molluskenkunde* 105: 1-423.
- BURCH, J. B. 1975. 'Freshwater unionacean clams (Mollusca: Pelecypoda) of North America'. (Malacological Publications: Michigan).
1982. 'Freshwater snails (Mollusca: Gastropoda) of North America'. (United States Environmental Protection Agency: Cincinnati).
- CAMPBELL, I.C. 1981. Biogeography of some rheophilous aquatic insects in the Australian region. *Aquatic Insects* 3: 33-43.
- CHILCOTT, S.J. 1987. Freshwater invertebrates. Pp. 12-18. In Fulton, W. & Richardson, A.M.M. (eds), 'The freshwater fauna of the World Heritage Area, Tasmania'. (Occasional Report 87-01, Inland Fisheries Commission: Hobart).
- CLARKE, A.H. (ed.) 1970. Papers on the rare and endangered mollusks of North America. *Malacologia* 10: 1-56.
- CLARKE, B., MURRAY, J. & JOHNSON, M.S. 1984. The extinction of endemic species by a program of biological control. *Pacific Science* 38: 97-104.
- COLE, G.A. 1968. Desert limnology. Pp. 423-486. In Brown, G.W. (ed.), 'Desert biology'. Vol. 1. (Academic Press: New York).
- COLEMAN, D.J. 1978. 'Lower Gordon scientific sur-



- vey. Downstream effects of the Gordon Dam.' (Hydro-Electric Commission: Hobart).
- COLGAN, D. J. & PONDER, W. F. 1994. The evolutionary consequences of restrictions in gene flow: examples from hydrobiid snails. *Nautilus*, Supplement 2 (in press).
- DANIELL, A. 1994. Genetics and terrestrial mollusc conservation. *Memoirs of the Queensland Museum* 36: 47-53.
- DAVIS, G.M. 1979. The origin and evolution of the gastropod family Pomatiopsidae, with emphasis on the Mekong River Triculinae. *Academy of Natural Sciences of Philadelphia. Monograph* 20: 1-120.
- DE DECKKER, P. 1986. What happened to the Australian aquatic biota 18 000 years ago? Pp. 487-496. In De Deckker, P. & Williams, W.D. (eds), 'Limnology in Australia.' (CSIRO: Melbourne; W. Junk: Dordrecht).
- GROOMBRIDGE, B. (ed.) 1992. 'Global biodiversity, Status of the earth's living resources.' (Chapman & Hall: London).
- HADFIELD, M.G. 1986. Extinction of Hawaiian achatinelline snails. *Malacologia* 27: 67-81.
- HARRIS, C. 1981. Oases in the desert: the mound springs of northern South Australia. *Proceedings of the Royal Geographical Society of Australasia, South Australian Branch* 81: 26-39.
1993. Mound springs: South Australian conservation initiatives. *Rangelands Journal* 14: 157-173.
- HERSHLER, R. 1985. Systematic revision of the Hydrobiidae (Gastropoda: Rissoacea) of the Cuatro Ciénegas Basin, Coahuila, Mexico. *Malacologia* 26: 31-123.
- HERSHLER, R. & SADA, D.W. 1987. Spring snails (Gastropoda: Hydrobiidae) of Ash Meadows, Amargosa Basin, California-Nevada. *Proceedings of the Biological Society of Washington* 100: 776-843.
- IUCN CONSERVATION MONITORING CENTRE 1988. '1988 IUCN Red List of threatened animals.' (IUCN: Gland, Switzerland; Cambridge, U.K.)
- KING, R.D. & TYLER, P.A. 1982. Downstream effects of the Gordon River development, South-west Tasmania. *Australian Journal of Marine and Freshwater Research* 33: 431-442.
- LAKE, P.S., COLEMAN, D., MILLS, B. & NORRIS, R. 1977. A reconnaissance of pollution of the King River in the Comstock and Crotty area, western Tasmania. Pp. 157-173. In 'Landscape and Man Symposium'. (Royal Society of Tasmania: Hobart).
- MALCOLM, H.E. 1987. Invertebrate fauna of the Franklin River area, Tasmania. Report on the Tasmanian and New Zealand Scientific Exploration Society (ANZSES) expedition 1983. *The Tasmanian Naturalist* 91: 1-7.
- MEAVE, J., KELLMAN, M., MCDUGALL, A. & ROSALES, J. 1991. Riparian habitats as tropical forest refugia. *Global Ecology and Biogeography Letters* 1: 69-76.
- MICHAELIS, F. B. 1986. Conservation of Australian aquatic fauna. Pp. 599-613. In De Deckker, P. & Williams, W.D. (eds), 'Limnology in Australia.' (CSIRO: Melbourne; W. Junk: Dordrecht).
- MITCHELL, B.D. 1985. Limnology of mound springs and temporary pools south and west of Lake Eyre. Pp. 51-63. In Greenslade J., Joseph, L. & Reeves, A. (eds), 'South Australia's mound springs.' (Nature Conservation Society: Adelaide).
- PONDER, W.F. 1982. Hydrobiidae of Lord Howe Island (Mollusca: Gastropoda: Prosobranchia). *Australian Journal of Marine and Freshwater Research* 33: 89-159.
1985. South Australian mound springs. Relict faunas in the desert. *Australian Natural History* 21: 352-355.
1986. Mound springs of the Great Artesian Basin. Pp. 403-420. In De Deckker, P. & Williams, W.D. (eds), 'Limnology in Australia.' (CSIRO: Melbourne; Junk: Dordrecht).
1988. *Potamopyrgus antipodarum* — a molluscan coloniser of Europe and Australia. *Journal of Molluscan Studies* 54: 271-285.
1989. Mollusca. Pp. 71-77. In Zeidler, W. & Ponder, W.F. (eds), 'Natural history of Dalhousie Springs' (South Australian Museum: Adelaide).
1992. Bias and biodiversity. *Australian Zoologist*, 28: 47-51.
- PONDER, W.F., CHILCOTT, S.J., FULTON, W., KIRKPATRICK, J. & RICHARDSON, A.M.M. 1994a. Streams and rivers in the World Heritage area of South Western Tasmania. Pp. 114-122. In Smith, S.J. & Banks, M.R. (eds), 'Tasmanian wilderness — World Heritage values'. (Royal Society of Tasmania: Hobart).
- PONDER, W.F. & CLARK, G.A. 1990. An endemic radiation of hydrobiid snails from endangered artesian springs in western Queensland. *Records of the Australian Museum* 42: 301-363.
- PONDER, W.F., CLARK, G.A., MILLER, A. & TOLUZZI, A. 1993. On a major radiation of freshwater snails in Tasmania and eastern Victoria — a preliminary overview of the *Red-domeia* group (Mollusca: Gastropoda: Hydrobiidae). *Invertebrate Taxonomy* 7: 501-750.

- PONDER, W.F. & COLGAN, D. J. 1992. The tyranny of distance — genetic differentiation of hydrobiid snails in streams and springs. P. 219. In Giusti, F. & Manganelli, G. (eds), 'Abstracts of the 11th International Malacological Congress, Siena 1992'. (University of Siena: Siena).
- PONDER, W.F., COLGAN, D. J., CLARK, G. A., MILLER, A. C. & TERZIS, T. 1994b. Microgeographic genetic and morphological differentiation of freshwater snails — a study on the Hydrobiidae of Wilsons Promontory, Victoria, south eastern Australia. *Australian Journal of Zoology* 42(4) (in press).
- PONDER, W.F., HERSHLER, R. & JENKINS, B.W. 1989. An endemic radiation of hydrobiid snails from artesian springs in northern South Australia: their taxonomy, physiology, distribution and anatomy. *Malacologia* 31: 1-140.
- RICHARDSON, A.M.M. & SWAIN, R. 1978. 'Freshwater invertebrates. Lower Gordon River Scientific Survey'. (Unpublished report, Hydro-Electric Commission, Hobart).
- SMITH, B.J. & KERSHAW, R.C. 1981. 'Tasmanian land and freshwater molluscs'. Fauna of Tasmania handbook, 5. (University of Tasmania: Hobart).
- SOLEM, A. 1988. Maximum in the minimum: biogeography of land snails from the Ningbing Ranges and Jeremiah Hills, northeast Kimberley, Western Australia. *Journal of the Malacological Society of Australia* 9: 59-113.
1990. How many Hawaiian land snail species are left and what can we do for them? *Bishop Museum Occasional Papers* 30: 27-40.
- SWAIN, R. & WHITE, R.W.G. 1985. Influence of a metal-contaminated tributary on the invertebrate drift fauna of the King River (Tasmania, Australia). *Hydrobiologia* 122: 261-266.
- WELLS, S.M. 1986. Priorities in mollusc conservation. *Proceedings of the 8th International Malacological Congress, Budapest 1983*: 291-294.
- WILLIAMS, W.D. 1974. Introduction. Pp. 3-15. In Williams, W.D. (ed.), 'Biogeography and ecology in Tasmania'. *Monographiae Biologicae* 25. (Junk: The Hague).
- YEN, A.L. & BUTCHER, R.J. 1992. Practical conservation of non-marine invertebrates. *Search* 23: 103-105.
- ZEIDLER, W. & PONDER, W.F. (eds) 1989. 'Natural history of Dalhousie Springs.' (South Australian Museum: Adelaide).

## INVERTEBRATE BIODIVERSITY CONSERVATION EDUCATION EXPERIENCE WITH A BENDIGO PRIMARY SCHOOL

JENNIFER M. SHIELD AND SUSAN HARRISON

Shield, J.M. & Harrison, S. 1994 06 30: Invertebrate biodiversity conservation education: experience with a Bendigo primary school. *Memoirs of the Queensland Museum* 36(1): 197-201. Brisbane. ISSN 0079-8835.

Targeting primary school children for invertebrate conservation education could be an effective strategy for promoting conservation of invertebrate biodiversity because both children and parents become informed. In 1993, at Bendigo, a class of primary school children aged 9 to 10 years studied invertebrates in a small sanctuary of Box Ironbark woodland on the school site. Educational objectives included increasing the children's knowledge of the inhabitants of the reserve and, through the experience, learning to appreciate the wonder and value of the nature reserve. Weekly field-based lessons focused on the diversity of invertebrate species, especially those that lived under rocks and on two local species of trees. The children participated in the lessons, particularly the field classes, with enthusiasm. They also carried out their observations with purpose. Their new appreciation for common plant species and their new interest in the bush and its miniature world were demonstrated in their oral and written work. The major difficulty we encountered was the lack of field guides for local invertebrates. For education, this lack of suitable literature needs to be rectified urgently. The development of regional booklets is an important area of community education that deserves funding support. □ *Environmental education, school, invertebrate, survey, biodiversity, conservation, Victoria, Australia.*

Jennifer M. Shield, Division of Biological and Chemical Sciences, Bendigo Campus, La Trobe University, PO Box 199, Bendigo, Victoria 3550, Australia; Susan Harrison, Spring Gully Primary School, Spring Gully Rd, Bendigo, Victoria 3550, Australia; 27 July 1993.

An essential strategy in the conservation of Australia's invertebrate diversity is effective community education. It is urgent that the importance of invertebrates and their diversity become more widely appreciated by the total community to ensure strategies are enacted to maximise the survival of Australia's invertebrates.

Primary schools are useful focuses for community education. Children are naturally inquisitive, they have good visual abilities, they enjoy working outdoors and they pass on information to their parents. Also, there is potential for whole community education through school newsletters.

The strategy of targeting primary school children for community education programs is not new. Examples include the Gould League in Victoria, which produces conservation education materials (including posters and guides, e.g. Miller, 1983), much of which are appropriate for primary school children; Saltwatch Programs in Victoria, which involve school children in monitoring salinity (Anon., 1993); and the CSIRO, which has involved children through the Double Helix Science Club in a national

earthworm survey (Anon., 1992). However, conservation of invertebrates does not usually have a high profile in nature conservation studies in our schools and much more could be done.

This paper reports an experience of invertebrate biodiversity education in a primary school based on field work in a school sanctuary.

### METHODS

During Semester 1, 1993, JMS, a biologist, worked with SH, a primary school teacher, and her class of children aged from 9 to 11 years, students of Spring Gully Primary School, Bendigo, Victoria.

The school has a small reserve within the school grounds known as *The Sanctuary*, which has been set aside in the school plan. It consists of a small area (less than one hectare) of regenerated Box Ironbark woodland situated on top of a ridge with outcrops of hard sandstone. The area has a high structural and species diversity and low weed invasion. It features many small rocks which provide shelter for ground dwelling invertebrates. The school's Sanctuary

is becoming increasingly isolated both by encroaching suburban development and by the continued development of the school grounds as the number of enrolments at the school grow.

The lessons on invertebrates had the following educational objectives:

#### Cognitive

Children developed their skills in the following areas:

- methods of looking for invertebrates in the Spring Gully Primary School Sanctuary,
- methods of handling invertebrates safely (both for the children and the animals),
- book research for invertebrate identification, life cycle and ecological information,
- discrimination in telling the animals apart and naming them,
- classification by sorting into species and higher order groupings,
- oral reporting by sharing their findings with the rest of the class,
- written reporting by listing animals found, sizes, numbers and where found and
- group skills by working in small groups of two or three.

#### Affective

The children developed their interest in invertebrates by their discovery of many different kinds in the Sanctuary and that common plants house many different species.

The children learnt about conservation of invertebrates and conservation of the Sanctuary by

- carrying out observation in situ as much as possible,
- replacing disturbed rocks and logs to exactly the same place and
- returning collected animals as soon as possible to the exact spot from where they were collected.

The program consisted of weekly sessions of approximately one hour when JMS was present, reinforced by use of the Sanctuary as a theme for some of the other class work during the week (SH). Apart from the introductory session and occasional wet weather, all the sessions were based in the field.

The first two field sessions were used for discovery and were restricted to in situ observations and observations under rocks. A sample beating of *Cassinia arcuata* (known in the Bendigo district as Chinese Scrub, but listed by Cleary & Leamon [1988] as Drooping Cassinia) and a search of a litter sample was also performed.

The lessons then focused on invertebrates oc-

curing on *C. arcuata* and *Acacia pycnantha* (Golden Wattle) and a number of particular invertebrate species chosen by the children. *C. arcuata* and *A. pycnantha* are both common pioneer shrubs in the Bendigo area. *C. arcuata* is regarded as a weed by many residents and, until recently, was on the noxious weeds list for some areas of Victoria.

Children collected from particular plants of the preceding two species by beating. They took the collection into the classroom for listing, measurement and counting and returned the collection to the plant at the end of the session. Where the animals could not be identified, the children gave each species a name. The information was recorded on prepared data sheets.

The children used a number of guides for identification of the animals collected: Child (1965), Clyne (1969), Main (1964) and Mascord (1970) for spiders; and Goode (1980) and Healy & Smithers (1971) for insects. CSIRO (1991) was consulted by the teachers.

## RESULTS AND DISCUSSION

#### CONSERVATION EDUCATION

The children became enthusiastic about invertebrates early in the project. They readily learnt whatever information was available for the species they were observing.

Field-based sessions were more widely appreciated than classroom sessions. The children were learning to think about the miniature world and the place of the different species in the food chain.

The children observed that many species of invertebrates live on a single plant of *C. arcuata* or *A. pycnantha*, and realized the importance of the plant as a habitat for animals. Most species found on *C. arcuata* were the same as those found on *A. pycnantha*. It was impossible to be sure whether there was a significant difference in inhabitants between the two plant species because of problems with identification (see below). Table 1 gives an incomplete comparative list of insects and spiders derived from two trappings a month apart. Only species identified at least to family level were included.

In all, the children appreciated the diversity of invertebrates that live in the patch of bush at their school.

#### GENERAL EDUCATION

The children used their discrimination skills effectively. They readily recognized animals

TABLE 1. Invertebrates occurring on *Cassinia arcuata* and *Acacia pycnantha*. Species were included in the table only if they were identified at least to family.

		<i>Cassinia arcuata</i>	<i>Acacia pycnantha</i>
<b>Araneae</b>			
Araneidae			
brown and green spiderlings		yes	yes
turret spider	<i>Dolophones turrigera</i>	no	yes
Thomisidae			
green flower spider	<i>Hedana valida</i>	yes	yes
white, large abdomen		yes	no
Oxyopidae			
choc chip spider	<i>Oxyopes</i> sp.	yes	yes
Clubionidae			
cappuccino choc chip spider	<i>Cheiracanthium</i> sp.	yes	yes
Salticidae			
jumping spider		yes	yes
<b>Insecta</b>			
Collembola			
spring tail		yes	yes
Hemeroptera			
brown lacewing larva		yes	yes
Cicadidae			
green grocer cicada	<i>Cyclochila australasiae</i>	no	yes
Eurytomidae			
fluorescent green leaf hopper		yes	no
Pentatomidae			
green vegetable bug		yes	no
brown horned bug with central dorsal white spot	<i>Omyta centrolineata</i>	yes	no
Psyllidae			
psyllid		no	yes
Flatidae			
green leafhopper with green opaque wings	<i>Siphanta acuta</i>	yes	no
Blattidae			
little black cockroach nymph with white dorsal spots		yes	no
Geometridae			
looper caterpillar		yes	no

that they had seen before, even though many of them were only a few millimetres in length.

Children of diverse abilities found success. Children in each group could share the tasks required according to their individual skills if necessary.

Males and females participated equally and sex roles were broken down. Early in the program, some boys would show off by handling the hairy caterpillars, while some of the girls would hang back; later, both boys and girls were equally keen to handle the animals and all seemed to respect them more.

The children's increased appreciation for invertebrates and the Sanctuary was demonstrated in their written work, particularly in poems, posters and articles which were written for the class newsletter. Figure 1 is a poster drawn in colour by two of the children when asked to express what they liked most about their school. It expresses a reluctance to leave the Sanctuary and its scorpions and birds when the teacher says that it is time to return to the classroom.

One of the poems concludes this paper. It demonstrates both an appreciation of biodiversity and a sense of wonder of life in the Sanctuary. One of the children, Nathan Smith, largely on his own initiative, carried out a survey of attitudes of other teachers on the staff to *C. arcuata*. In his small sample of six, he found that three considered it to be a weed and would remove any plants of this species from their backyard; one was not sure; and two thought it was important and would retain it in their backyard.

#### PROBLEMS

There were several problems. Difficulties were experienced in identifying the animals. Insufficient information on terrestrial invertebrates is available at a level that can be used by community members or children (see also Czechura, 1994). The problem was exacerbated by our policy of putting the invertebrates back at the end of each lesson.



FIG. 1 This poster was made by Robert Steele and Geoffrey Mattheson in response to a request to say what they liked most about their school. The original was in colour and A3 size.

Because we had no reference collection and few illustrations of the species encountered, we could not be confident that all the children were calling the same species by the same name. Because the children worked in small groups, not all the people in the group, including the adults, saw the specimens together with the children's names before the animals were returned to the Sanctuary. In some cases, different forms of the same species might have been listed under different names by the children, e.g. the green flower spider (*Hedana valida*) on the same day was referred to as 'spearmint' by one group and 'green fluoro spider' by another group.

We were concerned that frequent use of the Sanctuary would adversely impact on organisms in the reserve, particularly small plants such as orchids and litter animals. We also suspected that some of the animals were not re-establishing themselves after they were returned to the reserve because later collections included some dead specimens.

There was evidence that the knowledge of how to find invertebrates had spread to other children

in the school, but the knowledge of how to conserve them did not. Rocks in the Sanctuary were disturbed by other children but were not replaced with the result that some of the animals being monitored could not be found again.

We were also concerned about the safety of the children with poisonous species.

## CONCLUSIONS

Our experience indicates that the program was beneficial to the children involved. Future extensions of the program are being investigated.

Our experience also indicates that it is impossible to carry out a study of this kind without making at least a small reference collection of identified specimens that can be used for comparisons. A major drawback to invertebrate biodiversity community education is that insufficient resources are available to allow ready identification of many common species by community members. The most useful books — Clyne (1969), Healy & Smithers (1971) and Mascord (1970) — had clear, coloured

photographs, which could be readily recognized by the children. However, an insufficient number of the species found in the Sanctuary were illustrated in these books.

For education about invertebrates, the lack of suitable literature needs to be rectified urgently. The development of regional booklets, such as are currently available for plants (e.g. Cleary & Leamon, 1988), is an important area of community education that deserves funding support.

#### LITERATURE CITED

- ANON. 1992. Earthworms downunder. *Helix* 26: 17.  
 ANON. 1993. Saltwatch builds on success. *Salt Force News* 31: 1.  
 CHILD, J. 1965. 'Australian spiders.' (Periwinkle Press: Melbourne).  
 CLEARY, J. & LEAMON, E. (eds) 1988. 'Wildflowers of Bendigo.' (Bendigo Field Naturalists Club: Bendigo).  
 CLYNE, D. 1969. 'A guide to Australian spiders.' (Thomas Nelson: Sydney).  
 CZECHURA, G.V. 1994. Is the public really interested in invertebrates? What the Queensland Museum Reference Centre enquiries from 1986-1993 tell us. *Memoirs of the Queensland Museum* 36: 41-46.  
 GOODE, J. 1980. 'Insects of Australia.' (Angus & Robertson: Sydney).  
 CSIRO 1991. 'Insects of Australia.' 2nd ed. Vol. 1&2. (Melbourne University Press: Melbourne).  
 HEALY, A. & SMITHERS, C. 1971. 'Australian insects in colour.' (Reed Books: Sydney).  
 MAIN, B.Y. 1964. 'Spiders of Australia.' (Jacaranda: Brisbane).  
 MASCORD, R.M. 1970. 'Australian spiders in colour.' (Reed Books: Sydney).  
 MILLER, R. 1983. 'Freshwater invertebrates.' (The Gould League of Victoria: Melbourne).

#### LOOK

Ants, spiders, everywhere  
 Crawling up legs and  
 Preying for food.  
 LOOK at that!  
 There's a scorpion  
 With its several  
 Babies on its back.  
 Isn't the Sanctuary a wonderful place  
 When you come to think of it?

RHIANNON CAHILL



## PARASITE EXTINCTIONS — WHY CARE?

LESLEY R. SMALES

Smales, L.R. 1994 06 30: Parasite extinctions — why care? *Memoirs of the Queensland Museum* 36(1): 203-206. Brisbane, ISSN 0079-8835.

If a host becomes extinct, does it matter that its parasites also become extinct? At least half the world's biota is parasitic, therefore it would seem important to understand the role of parasites within ecosystems. As case studies, the unique, parasitic fauna of two endangered Australian mammals — the Northern Hairy-nosed Wombat (*Lasiorhinus krefftii*) and the False Water Rat (*Xeromys myoides*) — provide insights into the question. In each case, parasite biogeography gives additional data on host origins, speciation patterns or host behaviour. As well, management strategies that involve controlling or eliminating parasite infections may be in error, because a parasite becoming extinct before its host might have a negative effect on host conservation. □ *Parasites, biogeography, host-parasite relationships, conservation, endangered, Xeromys, Lasiorhinus, Queensland, Australia.*

Lesley R. Smales, Department of Biology, University of Central Queensland, Rockhampton 4702, Queensland; 30 July 1993.

It is generally accepted by parasitologists — although rarely acknowledged by others — that there are more parasitic species than non-parasitic ones. This is thought to be true even when viruses, rickettsias, bacteria and fungi are discounted (Schmidt & Roberts, 1989). Thus, if at least half the world's biota is parasitic, and those organisms that are not parasitic are hosts (Schmidt & Roberts, 1989), then parasites must form a major part of the diversity of life. Furthermore, because this diversity is the foundation for the continued existence of a healthy planet (Biodiversity Unit, 1993), then parasites must be very important.

Recent analyses of biodiversity (Stork & Gaston, 1990; Lewin, 1991) suggest that more species of insects have been described — and more are awaiting description — than for any other group. Be that as it may, every kind of insect that has been examined has harboured at least one species of parasitic nematode, as well as other ecto- and endo-parasites. Therefore, there are probably as many parasite species awaiting description as insects. Consequently, there should be at least as much concern about undescribed parasites as there is for the insects.

So what attention has been paid to parasites in the biodiversity debate? It seems that although invertebrates are now being valued as species in their own right (or as flagship species or indicators of environmental health), the role of parasites in ecological systems continues to be largely ignored. As Munger & Karasov (1991) noted, theoretical work in the late 1970's sparked

some interest in the regulation of host abundance by parasites. Studies of host-parasite interactions, however, provided only limited insight into the role of parasitism within ecosystems.

Parasitologists are now becoming more sensitive to the issue of parasite extinction. For example, 'EQUAL RIGHTS FOR PARASITES' was used by Windsor (1990) to draw attention to their importance. Parasite species are not simply pathogenic agents but species with their own evolutionary value.

Parasites are the ubiquitous, yet usually invisible component of animal communities .... they influence population dynamics of host species and hence influence the diversity and abundance of organisms in the environment (Minchella & Scott, 1991).

Even so, attention has more often been caught by the plight of a rare or endangered host species than the possible extinction of its parasites.

The following two case-studies illustrate that rare, host species can harbour rare species of parasites, and that understanding the inter-relationship of the host and the parasite is important. These parasites have only been recently discovered.

### ENDANGERED SPECIES

#### NORTHERN HAIRY-NOSED WOMBAT

The first case study is a nematode (Cloacinidae) parasitic in the colon of the Northern Hairy-nosed Wombat (*Lasiorhinus krefftii*).

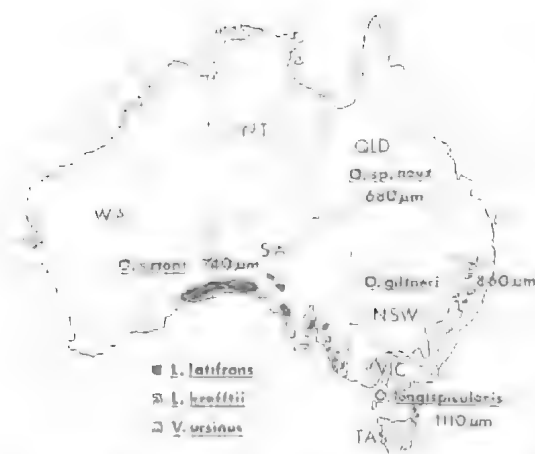


FIG. 1. The distribution of wombats in Australia compared with the distribution of *Oesophagostomoides* spp. Mean spicule lengths of the nematode species are given.

This host is one of Australia's most endangered mammals, known from a single colony of about 70 individuals in Epping Forest National Park, north-west of Rockhampton, Central Queensland. It, *L. latifrons* (Southern Hairy-Nose) and the Common Wombat (*Vombatus ursinus*) comprise the living Vombatidae; five other wombat genera are known to be extinct (Wells, 1989). Hairy-nosed wombats can be distinguished from Common Wombats by their hairy (not smooth) noses, larger ears, silky coats and skull features (Wells, 1989). Northern and Southern Hairy-noses can be distinguished from each other by differences in skull features (Wells, 1989) and helminth parasites.

Wombat distribution has been considerably reduced since European settlement (Fig. 1). During the late Tertiary to Pleistocene, the Common Wombat occupied the coastal margins and ranges from SW Australia and Tasmania, north to southern Queensland, while the hairy-nosed species preferred drier, inland conditions (Wells, 1989). Wombat species probably overlapped at the margins of their ranges, for example fossil evidence of *L. krefftii* has been found in known *V. ursinus* range (Gordon, 1991).

Northern Hairy-nosed Wombats spend the day in their burrows, making it difficult to retrieve dead bodies or dying animals for further study. However, a juvenile male was discovered in a moribund condition by a National Parks ranger in 1991. The animal's body was frozen and sent to the Queensland Museum. There it was fixed in

10% formalin and then stored in alcohol. Cestodes were found in the small intestine and nematodes in the colon.

The only previous record of a parasite from *krefftii* is a cestode, recorded in 1923 as *Paramoniezia suis*, a species normally found in pigs. Beveridge (1976) suggested it was probably *P. johnstoni*, the cestode usually found in *V. ursinus* and *L. latifrons*. Unfortunately the poorly preserved material made definite identification impossible and the identity of the cestode fauna of the Northern Hairy-nosed Wombat therefore remains confused.

The nematodes (149mm ♂♂ and 278 ♀♀) probably represent an undescribed species of *Oesophagostomoides*. This stronglylid genus is exclusive to wombats, and includes two species from the Common Wombat and one from the Southern Hairy-nosed Wombat. All four species are similar at the anterior end, having a cylindrical buccal capsule; an external leaf crown of 8 elements and internal leaf crown of 16-32 elements; and in having the duct of the oesophageal gland pierce the wall of the buccal capsule, divide internally and form an encircling groove (Fig. 2A). It appears that these new specimens cannot be identified as any known species since they differ in the following characters: the proportions of the tail and the position of the vulva in the female; and the length of the spicule (Fig. 1) and the shape of the dorsal ray and gubernaculum in the male.

It would be interesting to compare speciation within *Oesophagostomoides* with wombat speciation to confirm patterns of co-evolution of host and parasite, but a full range of comparative morphological and molecular data for phylogenetic analysis will be difficult to get. Questions about the relationships between the host and the parasite species, and the extent to which they have co-evolved, remain unanswered.

These questions, however, are critical for wombat conservation. For example, to what extent is this tiny remnant of hairy-noses threatened by disease and are its parasites a threat to its very survival? Are the wombats and the parasites in a symbiotic relationship? (see also Bryant, 1992). Are both an integral component of each other's ecology?

The answers are important. A management strategy that involves controlling or eliminating parasite infections may be in error because, if a parasite becomes extinct before its host, there might be a negative effect on the conservation of

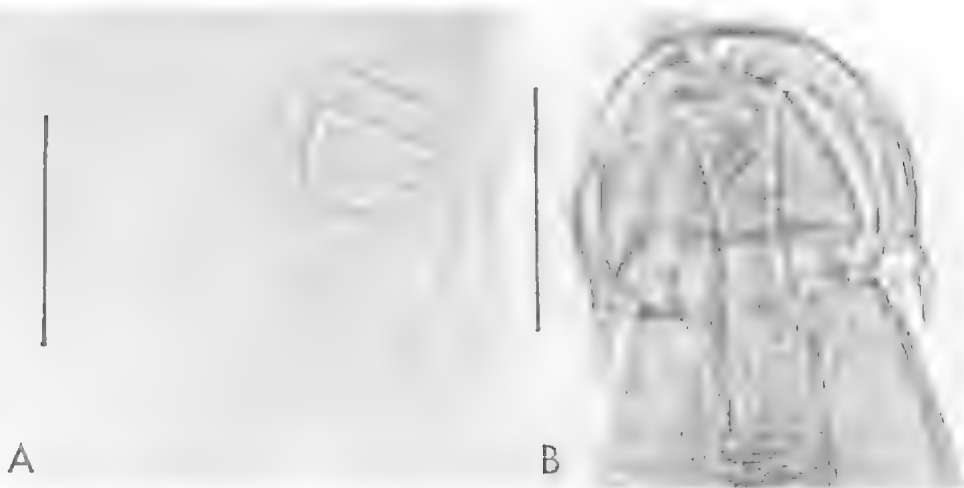


FIG. 2. A, Photomicrograph of the anterior end of *Oesophagostomoides* n.sp. from *Lasiarhinus latifrons*. Scale line 0.1 mm. B, photomicrograph of the anterior end of the nematode from *Xeromys myoides*. Scale line 0.1 mm.

the host (Rózsa, 1992). Parasites exert selective pressure on their hosts — so saving a host without its parasites might result in a decline of intraspecific genetic diversity, ultimately affecting the survival potential of the host (Rózsa, 1992).

Population geneticists build mathematical models to predict the size of minimum, viable populations to help conservationists design management programs. There is little doubt, however, that these models will be unreliable without accounting for the effects of parasites.

#### FALSE WATER RAT

An acuariod nematode living in the stomach of the False Water Rat (*Xeromys myoides*) is the other case study. The False Water Rat is the only species in a distinctive Australian genus. It resembles several Papua New Guinean rodent species in morphology and ecology and may be a relatively recent (in evolutionary terms) invader from Papua New Guinea (Watts & Aslin, 1981). *X. myoides* is known from only six localities and it was listed by the Council of Nature Conservation Ministers in 1991 as a vulnerable species (Van Dyck, 1992). Until 1992, there were only 14 specimens held in museums with a further 12 individuals observed or trapped-and-released in the wild (Van Dyck & Durbidge, 1992). The diet of the rat includes marine invertebrates such as crabs, mud-lobsters, mussels, marine pulmonates and polyclads (Van Dyck, 1994).

Nematodes were found in the stomachs of four out of four Queensland Museum specimens, which had been fixed in 10% formalin and subsequently examined for parasites. The specimens

might represent an undescribed species. Their generic allocation, however, is in dispute. Two different groups of workers have described two similar (probably synonymous) species from *Rattus argentiventer* (Rice Field Rat) from Java. Moreover, because of the authors' differing interpretations of the features of the anterior end of the nematode, the worms were assigned to different genera: *Tikusnema* (Hasegawa et al., 1992) and *Molinacuaria* (Gibbons et al., 1992). The specimens from *X. myoides* have similar features to both described species but differ in proportions. As well, the cuticular leaves of the pseudolabia differ in shape (Fig. 2B).

It is not known whether there is a connection between Rice Field Rats from Java and False Water Rats from Australia. The presence of closely related nematodes in these two, now widely geographically separated hosts, could provide further clues to the origins of *Xeromys*. If there are similar parasites in Papua New Guinean rodents, it will add weight to the suggestion that *Xeromys* is a relatively recent arrival from Papua New Guinea.

Acuariod life-cycles invariably include arthropods as intermediate hosts (Schmidt & Roberts, 1989). The presence of an acuariod parasite, at a high prevalence, in the False Water Rats is therefore an indicator of the importance of crustaceans in their diet.

#### CONCLUSION

Both these case studies illustrate the intrinsic interest in revealing as yet undiscovered parasite

fauna. They also illustrate the need for caution in determining conservation strategies for species in which parasites are yet unknown, and where host-parasite relationships are poorly understood. Until effects of parasitism on host demography, physiology, competition and predation are appreciated we cannot afford to ignore parasitic infestations. Attempts to tease out the effects of sub-lethal infections of parasites on populations of hosts (studies such as that on White footed Mice by Munger & Karasov, 1991) are difficult. The effects of presence or absence of infection on an individual host may be confounded by other factors, so that more questions are formulated than answered.

Equal rights for parasites, however, can be argued if the goal is to conserve all species, not just those with outward appeal. But, leaving such arguments of intrinsic worth aside, how can successful conservation strategies be developed for more obviously valued animals, if the parasites, which form an integral part of each ecological community, are not also conserved? The totality of the biosphere, including the usually invisible parasite component, must be maintained.

#### ACKNOWLEDGEMENTS

Thanks to Steve Van Dyck for making the hosts available for dissection and Heather Smyth for assistance with the figures.

#### LITERATURE CITED

- BEVERIDGE, I. 1976. A taxonomic revision of the Anoplocephalidae (Cestoda: Cyclophyllidae) of Australian Marsupials. Australian Journal of Zoology Supplementary Series 44: 1-110.
- BIODIVERSITY UNIT 1993. 'Biodiversity and its value.' Biodiversity Series, Paper 1:23. (Department of Environment Sport and Territories, Commonwealth of Australia: Canberra).
- BRYANT, C. 1992. Organic acid secretion by helminths. Parasitology Today 9: 58-60.
- GIBBONS, L.M. CRAWSHAW, M.T. & RUMPUS, A.E. 1992. *Molinacuaria indonesiensis* n.sp. (Nematoda, Acuarioidae) from *Rattus argentiventer* in Indonesia. Systematic Parasitology 23: 175-181.
- GORDON, G. 1991. The Northern Hairy-nosed Wombat. P.122. In Strahan, R. (ed.), 'The Australian Museum Complete Book of Australian Mammals'. (Collins, Angus & Robertson: North Ryde).
- HASEGAWA, H. SHIRAIISHI, S. & ROCHMAN, 1992. *Tikusnema javaense* n.gen., n.sp. (Nematoda: Acuarioidae) and other nematodes from *Rattus argentiventer* collected in West Java, Indonesia. Journal of Parasitology 78: 800-804.
- LEWIN, R. 1991. Too many insects, and not enough entomologists. New Scientist 1751: 15.
- MINCHELLA, D.J. & SCOTT, M.E. 1991. Parasitism: a cryptic determinant of animal community structure. Trends in Ecology and Evolution 6: 250-253.
- MUNGER, J.C. & KARASOV, W.H. 1991. Sublethal parasites in white footed mice: impact on survival and reproduction. Canadian Journal of Zoology 69: 398-404.
- RÓZSA, L. 1992. Endangered parasite species. International Journal for Parasitology 22: 265-266.
- SCHMIDT, G.D. & ROBERTS, L.S. 1989. 'Foundations of parasitology'. 4th ed. (Times, Mirror Mosby: St Louis).
- STORK, N. & GASTON, K. 1990. Counting species one by one. New Scientist 1729: 31-35.
- VAN DYCK, S. 1992. Parting the reeds on Myora's *Xeromys kibbutz*. Wildlife Australia 29(1): 8-10.
1994. The rats at Neptune's table. Australian Natural History 24(8): 30-37.
- VAN DYCK, S. & DURBIDGE, E. 1992. A nesting community of False Water Rats *Xeromys myoides* on the Myora sedgelands, North Stradbroke Island. Memoirs of the Queensland Museum 32: 374.
- WATTS, C.H.S. & ASLIN, H.J. 1991. 'The rodents of Australia'. (Angus & Robertson: London).
- WELLS, R.T. 1989. Vombatidae. Pp. 755-765. In Walton, D.W. & Richardson, B.J. (eds), 'Fauna of Australia. 1B. Mammalia'. (Australian Government Publishing Service: Canberra).
- WINDSOR, D.A. 1990. Heavenly hosts. Nature 348: 104.

## THE DISTRIBUTION AND PATTERNS OF SPECIES DIVERSITY OF LAND SNAILS IN EASTERN AUSTRALIA

JOHN STANISIC

Stanisic, J. 1994 06 30: The distribution and patterns of species diversity of land snails in eastern Australia. *Memoirs of the Queensland Museum* 36(1): 207-214. Brisbane. ISSN 0079-8835.

For coastal and near-coastal eastern Australia (Torres Strait islands to the New South Wales-Victorian border), it is predicted that the total number of species of land snails will exceed 700 (presently less than 400 are known) when taxonomic revisions are completed. Most of this snail diversity is concentrated in a coastal strip less than 200km wide. Species diversity and endemism is greatest for rainforest. The climate induced attrition of mesic communities since the Miocene (more pronounced in the Pleistocene), their survival within refugia and their subsequent radiation and dispersal under more favourable conditions, are fundamental to explaining how these diversity patterns arose. Endemism and species diversity of land snails in eastern Australia is also high on limestone outcrops. In an extraordinary situation in the Macleay Valley, northeastern New South Wales, rainforest and limestone are juxtaposed, resulting in diversity levels which are exceptionally high on a world scale.

Species composition within areas of high snail diversity indicates that these snail communities evolved through a long term accumulation of taxa rather than localised radiations. In a few cases, e.g. isolated dry vine thickets, between-site diversity is increased by geographic replacement of taxa.

Today the distribution of land snails in eastern Australia strongly reflects rainforest biogeography; furthermore land snail community structure correlates with rainforest structural types. This suggests that land snails can have strong predictive value in identifying climatic refugia. □ *Land snails, Mollusca, eastern Australia, biodiversity, communities, limestone, rainforest, distribution*

John Stanisic, Queensland Museum, PO Box 3300, South Brisbane, Queensland, 4101, Australia; 21 November 1993.

The study of land snail diversity in eastern Australia is in its infancy. Faunal checklists and species' descriptions have not been complemented by 'follow-up' survey work and revisionary studies. The works of Cox (1868) and Iredale (1937a, 1937b, 1938) still form the basis of terrestrial malacological knowledge for this region. Contemporary contributions of Smith & Kershaw (1979, 1981) focused on Victorian and Tasmanian species and more recently Smith (1992) produced a revised checklist of all Australian land snails. Attempts at 'modern' biogeographic syntheses are limited to McMichael & Iredale (1959), Solem (1959), Bishop (1981) and Smith (1984). With the exception of some rainforest surveys of the mid-1970's (e.g. Broadbent & Clark, 1976) and a survey of the New England district, New South Wales (Simpson & Stanisic, 1986), there has been a lack of comprehensive field work directed at recording and documenting the east-coast land snail fauna.

For the past thirteen years the Queensland Museum Malacology Section has been engaged in a systematic collection programme extending from the Torres Strait islands to the New South Wales/Victorian border in an effort to redress these shortcomings. More than 1000 sites (a site is an area <1km<sup>2</sup> in size) (Fig. 1) have been sampled by hand-collecting live and dead specimens and sorting retrieved leaf litter (land snails usually possess a hard shell), which remains in the litter after death and allows for post-mortem sampling). Results indicate that the diversity of the east-coast land snail fauna has been grossly underestimated. While a great deal of taxonomic work needs to be completed before a comprehensive biogeographic synthesis can be presented, preliminary findings make it possible to promote these often-neglected animals in the biodiversity debate. This paper examines some aspects of land snail diversity in eastern Australia which have come to light during the

course of the study.

The major physiographic features of the study area are the Great Dividing Range and a series of coastal ranges which rise from a narrow coastal plain to provide barriers to onshore, rain-bearing winds. Consequently, in addition to drier sclerophyll vegetation, these mountains support rainforest that varies in structure and extent from north to south (Webb & Tracey, 1981) and from sea level to mountain summit. In more westerly areas, rainforest in the form of dry vine thickets occurs sporadically on volcanic soils and rock outcrops, in particular limestone. Field work has been focused on censusing the snail communities within these habitats, which occur mainly in a narrow coastal strip less than 200km wide.

The following abbreviations have been used in the text: NSW, New South Wales; NEQ, north-eastern Queensland; MEQ, mideastern Queensland; SEQ, southeastern Queensland.

#### LAND SNAILS AND RAINFOREST

The association between land snails and moist, closed forests is an ancient one. Land snails make their first appearance in the fossil record in the Upper Carboniferous coal beds of Europe and North America and it has been suggested (Solem & Yochelson, 1979) their early radiation was closely tied to the appearance and proliferation of angiosperms. The basis for the association is ecological. Those factors which favour rainforests (high nutrient soils, moisture) are also those which favour land snails. Rainforests provide the additional benefit of shelter. In eastern Australia this bond has been more strongly reinforced by climatic and geologic events which shaped present-day, east-coast physiography.

Rainforest was once more widespread in Australia than today (Martin, 1981). With the onset of arid episodes in the Miocene (Galloway & Kemp, 1981), rainforest either disappeared or was restricted in distribution in many areas (Fig. 2). In the east, uplift of the Great Divide and volcanic activity combined to provide favourable moisture-soil conditions which ameliorated the effects of continental drying and allowed mesic communities to persist. Subsequently rainforest has fluctuated greatly in extent (Kershaw, 1980, 1981) and the extreme drying events of the Quaternary would have seen rainforest retreat to refugia such as moist uplands and gully heads, emerging only in wetter periods (Webb & Tracey, 1981). The animal communities within them, in particular the strongly moisture-dependent, soft-



FIG 1. Distribution of land snail collecting sites in eastern Australia, Queensland Museum 1980-1993 (Ca, Cairns; Ma, Mackay; Ro, Rockhampton; Br, Brisbane; Sy, Sydney).

bodied land snails, would have been placed under considerable stress. In some cases extinctions would have occurred.

The fact that most land snails in eastern Australia (over 90%) now occur in rainforest indicates just how critical the persistence of moist refugia was to their survival in this region.

Within the rainforest vegetation mosaic, snail diversity and community composition differ markedly with latitude and from site to site. The regions which have the greatest number of

FAMILY	Named species*	Estimated new species*
Hydrocenidae	4	5
Helicinidae	5	3
Cyclophoridae	2	2
Pupinidae	19	10
Diplommatinidae	4	3
Achatinellidae	3	0
Pupillidae	20	4
Enidae	1	1
Megaspiridae	1	1
Succineidae	3	1
Subulinidae	1	0
Rhytididae	27	8
Caryodidae	9	0
Helicodiscidae	1	0
Punctidae	13	7
Charopidae	74	200
Athoracophoridae	1	3
Cystopeltidae	4	2
Helicarionidae	46	40
Camaenidae	105	35
Corillidae	1	0
Rathouisiidae	2	0
TOTAL	347	325

TABLE 1. Faunal composition of eastern Australian land snail diversity (\*based on various sources; \*based on undescribed species identified in the collections of the Queensland Museum).

species are those with dissected topography (sleep gorges and high mountains) that support diverse rainforest vegetation communities (e.g. Wet Tropics, Border Ranges). Moisture stability and the availability of diverse niches have provided an ideal environment for the evolution and persistence of complex snail communities.

### LIMESTONE

Limestone outcrops (Fig. 2), in particular large tower karsts such as those present in the Chillagoe-Palmerville region, NEQ, north of Rockhampton, MEQ, and Jenolan, NSW, are significant secondary habitats for land snails. They support remnants of wet-adapted vegetation in otherwise dry, sclerophyll-dominated countryside. Moisture is trapped in crevices and

the rock provides a protective niche from wildfires so that in many instances snail communities, quite distinct from those in the surrounding forest, have developed and been maintained. Land snails which inhabit these special refugia also benefit from an ample supply of calcium. Endemicity and specialisation in these limestone snail communities indicate long-term isolation (Stanisic, 1990). In an exceptional case in the Macleay Valley, NENSW, subtropical/warm temperate rainforest and limestone are juxtaposed resulting in extraordinarily high land snail diversity.

### FAUNAL COMPOSITION

There are 22 families represented in the east-coast native land snail fauna comprising more than 670 species of which about half are undescribed (Table 1). This compares with estimates of a total Australian fauna of 504 species in 25 families (Smith, 1992) and illustrates the enormous diversity (mostly undescribed) of the east-coast fauna. It is probable that final species numbers for this region will exceed 700. The main contributors to this biodiversity are the Charopidae, Camaenidae and Helicarionidae. The Helicarionidae and Charopidae have their greatest expression in eastern Australia but the Camaenidae are more diverse in other areas of Australia (see Solem, 1992, for overview). The Australian operculate land snails (Hydrocenidae, Helicinidae, Cyclophoridae, Pupinidae and Diplommatinidae) are also largely confined to the east-coast rainforests. The stable moisture regime and volcanically derived acidic soils have provided an ideal environment for slug evolution and three families of slug taxa are represented — the Rathouisiidae, Cystopeltidae and Athoracophoridae. The first is an obligate rainforest group while the latter two have representatives in transitional wet sclerophyll forest as well as closed forests. Semi-slugs, belonging to the family Helicarionidae, display an even greater diversity here with over 30 species present, some restricted to mountain tops. The great majority of these are rainforest dwellers with only a few species occurring in drier sclerophyll forests.

Dry-adapted groups such as the Pupillidae and Punctidae have several representatives in the warm to hot humid forests but are more diverse in the drier vine thickets and forests, and sclerophyll forest.



## SITE DIVERSITY

Land snail diversity levels at individual collecting sites have been found to be highly variable and range from about 5 species per site in dry sclerophyll forests to over 40 species per site in some rainforest patches (Fig. 3). Greatest diversity has been recorded in the subtropical rainforests of southeastern Queensland. Binna Burra (Border Ranges) and Booloumba Creek (Conondale Ranges) have yielded in excess of 40 species. From this subtropical zenith diversity diminishes both to the north (tropical forest) and to the south (temperate forests). In most cases increased distance from the coast correlates with a marked drop in diversity so that subcoastal rainforest patches (= dry vine thickets) average about 10 species. Exceptions occur in isolated moist refugia such as those at Carnarvon Gorge, MEQ, and Mt Kaputar (Nandewar Range), NSW, and on limestone outcrops. Hence at Chillagoe, NEQ, more than 25 species have been recorded on limestone in otherwise snail depauperate countryside. In southern NSW limestone outcrops located in areas of sclerophyll woodland (e.g. Abercrombie, Yarrangobilly, Wombeyan, Jenolan) also record above average site diversity levels indicating the probability of highly localised endemism. In NENSW average rainforest site diversity levels are generally 10-20 species but in the Macleay River valley, where limestone occurs within rainforest, species numbers at some sites (Yessabah, 36; Mt Sebastopol, 26) are much higher owing to the presence of limestone endemics (Stanisic, 1990). There are few areas of the world where site diversity levels exceed 30 species (Solem, 1984). In this context eastern Australia is an area of exceptional land snail diversity.

## MOSAIC DIVERSITY

Dissected topography associated with the Great Escarpment (Ollier, 1982) and severe palaeoclimatic regimes have combined to produce a diverse pattern of vegetation communities in eastern Australia that support equally diverse land snail assemblages. The result is relatively high diversity within comparatively small areas even though diversity at individual sites is not high.

Mt Bellenden Ker is the second highest mountain (alt. = 1560m) in the Wet Tropics, NEQ. The eastern face is covered in rainforest which is altitudinally stratified into a number of structural

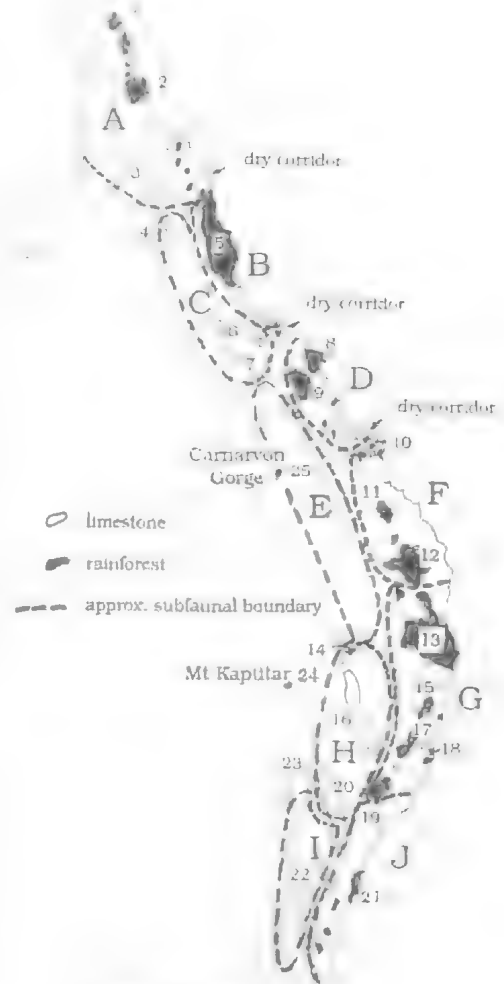


FIG. 2. Distribution of major coastal rainforest blocks and areas of limestone outcrop in eastern Australia. Dotted lines signify possible boundaries for division of land snails into subfaunal units (A-J). 1, Lockerbie Scrub; 2, Iron Range; 3, Palmerville; 4, Chillagoe; 5, Wet Tropics; 6, Greenvale; 7, Broken River; 8, Conway Range; 9, Eungella; 10, The Caves; 11, Bulburin; 12, Gympie; 13, Border Ranges; 14, Ashford; 15, Dorrigo; 16, Manilla-Tamworth; 17, Carrai-Werrikimbe; 18, Macleay Valley; 19, Barrington Tops; 20, Hill End-Captains Flat; 21, Illawarra; 22, Cowra-Yass; 23, Molong. A, Cape York; B, Wet Tropics; C, Einasleigh Uplands; D, mideastern Queensland; E, Brigalow Lands; F, southeastern Queensland; G, Border Ranges-northeastern NSW; H, New England Tablelands; I, Southern Tablelands; J, south coastal New South Wales.

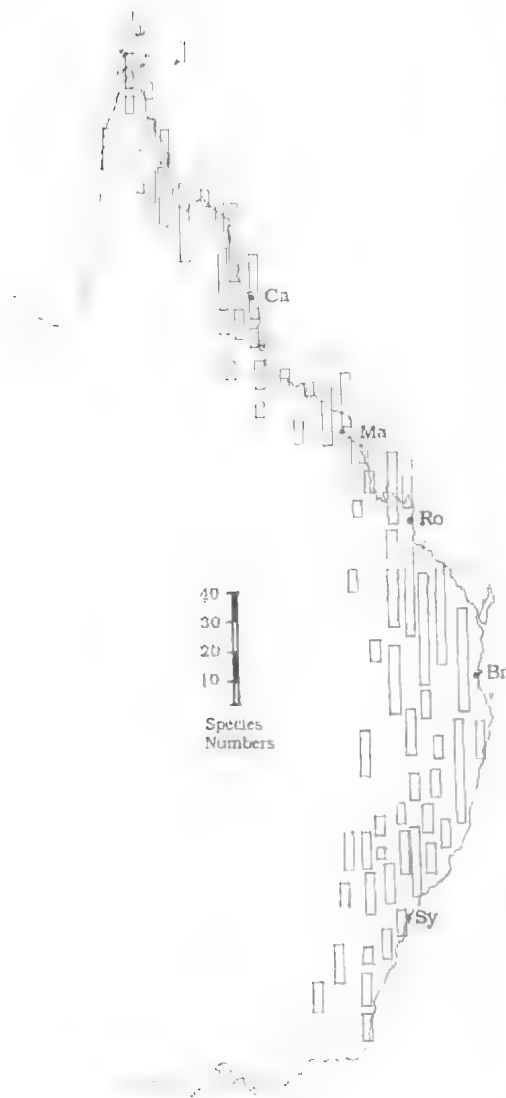


FIG. 3. Comparison of land snail diversity levels at selected sites in eastern Australia (Ca, Cairns; Ma, Mackay; Ro, Rockhampton; Br, Brisbane; Sy, Sydney).

types varying from complex mesophyll vine forest in the lowlands to simple microphyll vine fern forest and thicket near the summit (Fig. 4). Sampling at selected altitudes produced 45 species over all sites. However, few species were present at all altitudes (Fig. 3). Greatest disparity occurred between the base (100m) and the summit (1560m) sites which had only 5 of 37 species in common. This pattern of altitudinal stratifica-

tion is most marked in the Wet Tropics but is also present at other east-coast localities.

The usual patterns of land snail distribution, which strongly reflect the rainforest/woodland vegetation mosaic are complicated by the presence of limestone (Fig. 2). A large number of outcrops occur along the Great Divide in NSW but those in the Macleay Valley, NENSW, are perhaps the most significant. They are situated in the midst of temperate and subtropical rainforest and even the most easterly outlier (Yessabah) is vegetated by rainforest in spite of being surrounded by much drier countryside (Floyd, 1983). Fifty sites (Fig. 5) were sampled in a area bounded by the Hastings River (south), Nambucca River (north) and the Great Divide (west). Rainforest sites (those without limestone) yielded comparatively low numbers of species (mean 5.64 species/site) but limestone sites were far richer (31.00 species/site). In contrast eucalypt forest sites were relatively snail poor (mean 3.00 species/site). The high diversity found on the limestones results from a combination of widespread species found in surrounding rainforest and eucalypt woodland, and a significant number of limestone endemics (see Stanisic, 1990, for some examples). Some species are confined to individual outcrops. Total diversity was approximately 85 species in the sampled area and was composed of a number of quite distinctive assemblages which have developed under different micro-environments.

In the vine thickets west of Townsville to Sarina, NEQ, there is evidence of geographical replacement of species between widely separate rainforest patches. Individual patches have low species numbers (5-10 species) but diversity over the totality of patches exceeds this because of allopatric speciation. Solem (1984) reported a similar phenomenon in northwestern Australia.

#### REGIONAL DIVERSITY

Iredale (1937a) first applied the concept of regional diversity to Australian land snails. Although this scheme has received some support (McMichael & Iredale, 1959; Smith, 1984) there has been criticism of its predictive value (Bishop, 1981). Horton (1973) suggested that any zoogeographic subdivision of Australia should consider isolating barriers as well as the climate and vegetation of an area. The proposed methodology (based on bird distribution) has particular relevance to land snails in eastern Australia where their evolution has been driven

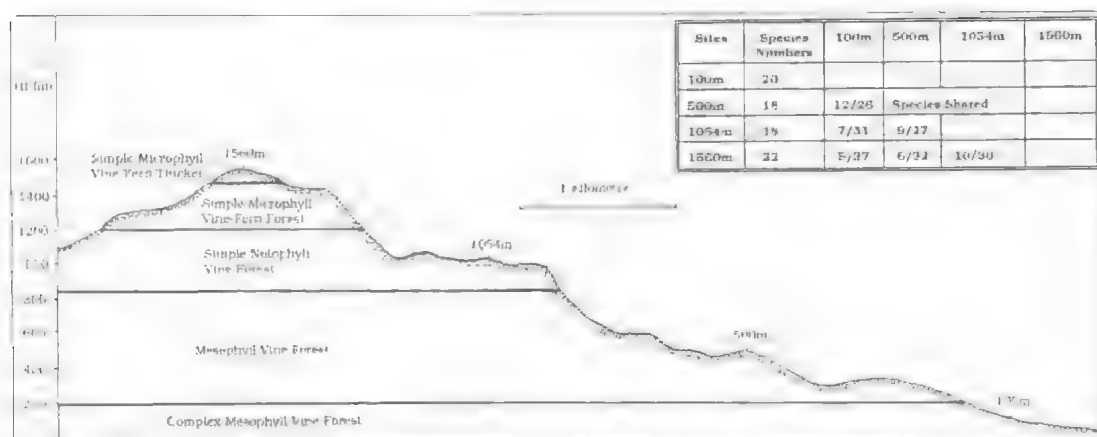


FIG. 4. Altitudinal stratification of land snail communities on Mt Bellenden Ker, NEQ (12/26 means that a total of 26 species were collected at 100m/500m sites and 12 were common to both).

by climate-based changes to mesic vegetation communities since the Miocene. A full outline of a scheme of land snail subfaunal units in eastern Australia will be presented elsewhere but the approximate boundaries of the units are shown in Figure 2. The proposed scheme divides the eastern Australian land snails into a number of smaller subregional units ('subfaunas') defined by a coincidence of species ranges and separated by species range endpoints (faunal breaks). These faunal breaks express past and present environmental discontinuities and may coincide with present climatic barriers (dry corridors) or, less obviously, reflect a more complex history of environmental sifting. Initial investigations indicate that the proposed land snail subfaunas in Queensland show considerable concordance with the natural biogeographic regions outlined by Stanton & Morgan (1977) which were defined by climate, vegetation and landform.

### COMMUNITY STRUCTURE

The species composition of land snail communities present at any site usually consists of narrow range endemics and species which have a more widespread distribution. The proportion of narrow range endemics is greatest in refugia (moist uplands, limestone outcrops) whereas widespread species tend to dominate drier vine thickets and eucalypt woodland. These land snail communities appear to be a result of an accumulation of species rather than localised radiations. In only a few cases can minor local radiations be identified, however, the wider picture is one of an ancient southern element complemented by a

colonising northern element. The southern element has more relicts in the north (most notably among the Charopidae) than vice versa. Charopids are numerically dominant in many places especially in areas of high diversity where site numbers can range 8-12 species. Sites with large numbers of charopids (whether in the north or south) or with any narrow endemic land snails are significant (Stanisic, 1990) because they indicate long-term moisture stability.

### DISTRIBUTION PATTERNS

Solem (1984) predicted that the median linear range for all land snail species would be considerably less than 100km (and probably less than 50km). Stanisic (1990) showed that a number of eastern Australian Charopidae had much more extensive ranges (150-200km). Most east-coast rainforest land snails show considerable breadth of distribution within major rainforest tracts (Wet Tropics; mideastern Queensland; araucarian vine forests of southeastern Queensland; Border Ranges etc.). Upland refugia and limestone outcrops have the greatest number of narrow range endemics. In drier vine thickets species can range over considerable distance but occur sporadically in isolated and scattered thickets. Species which live in eucalypt woodland tend to have the widest ranges. These features highlight the importance of refugia for land snail survival, the significance of the rainforest ecosystem in providing long-term moisture stability and the broad environmental adaptability of dry-adapted forms.

While it is possible to comment informatively

on local species richness, discussion of species abundance (numbers of individuals) remains largely qualitative and speculative. No formal study of land snail abundance (in time and space) has yet been attempted in eastern Australia.

Limestone sites and the araucarian vine forests of southeastern Queensland have the greatest numbers of species living sympatrically. However, because land snails have fairly specific microhabitat requirements the local abundance of a particular species will vary greatly depending on the degree of environmental heterogeneity (microhabitat diversity). Hence in MEQ large camaenids are dominant overall but reach greatest numbers in rocky talus slopes. On limestone outcrops the density of individuals is enhanced by the presence of sheltered southeasterly aspects along driplines. Many of the environments with high snail numbers are seasonally dry and fluctuations in local abundance may occur but this has not yet been quantified. In the Wet Tropics large camaenids do not appear to have the same local abundance as those which occur in MEQ so that locating large numbers of individuals is difficult. Similar situations have been encountered in the wetter forests of NENSW and SEQ. Reasons for this are not obvious. Solem (1984) suggested that there might be advantages

to the limited activity periods of land snails in drier environments. The effects of competitive interaction between and among species is unknown as are the effects of densities on population. There is a desperate need for basic ecological studies of eastern Australian land snails with particular emphasis on the aspect of abundance.

## CONSERVATION

As indicators of climatic refugia land snails appear to be a potentially significant group of organisms in the biodiversity/conservation debate. In spite of the large numbers of undescribed species, land snails represent a manageable taxonomic unit for use in land management decisions. Today their distributions reflect rainforest biogeography and in many instances land snail community composition correlates strongly with rainforest structural types. This suggests that land snails can have strong predictive value in identifying potential reservation areas.

## ACKNOWLEDGEMENTS

Data on the land snails of the Macleay Valley, NENSW, were collected as part of a larger project on the limestone Charopidae of NSW funded by ABRS. This financial assistance is gratefully acknowledged. These data were collated and analysed by Craig Eddie. Field work to Mt Bellenden Ker, NEQ, was funded by the American-based Earthwatch organisation. Thanks are also to Jennifer Mahoney for typing the manuscript.

## LITERATURE CITED

- BISHOP, M.J. 1981. 'The biogeography and evolution of Australian land snails' Pp. 924-954. In Keast, A. (ed.), 'Ecological biogeography of Australia'. (W. Junk: The Hague).
- BROADBENT, J. & CLARK, S. 1976. 'A faunal survey of east Australian rainforests: interim report'. (Australian Museum: Sydney).
- COX, J.C. 1868. 'A monograph of Australian land shells'. (W. Maddock: Sydney).
- FLOYD, A.G. 1983. 'Rainforest vegetation of the Yessabah limestone belt and Carrai Plateau', (Unpublished Internal Report, New South Wales National Parks and Wildlife Service, Sydney).
- GALLOWAY, R.W. & KEMP, E.M. 1981. Late Cainozoic environments in Australia. Pp. 52-80.

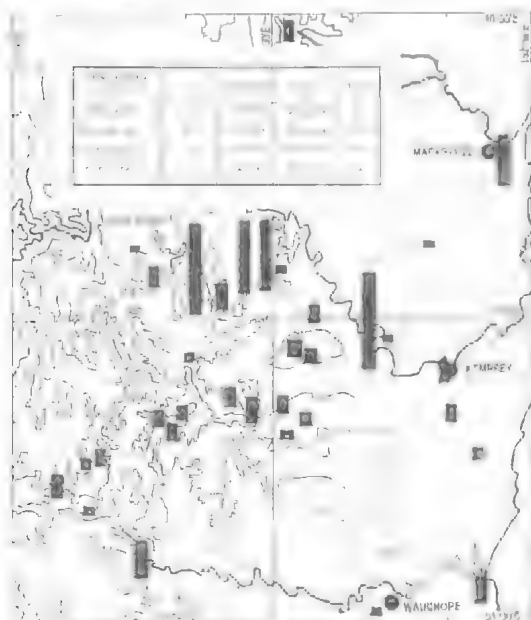


FIG. 5. The influence of limestone (four highest peaks in centre) on land snail site diversity levels in the Macleay Valley, NENSW (not all sites shown; rainforest sites are those without limestone).

- In Keast, A. (ed.), 'Ecological biogeography of Australia'. (W. Junk: The Hague).
- HORTON, D. 1973. The concept of zoogeographic subregions. *Systematic Zoology* 22: 191-195.
- IREDALE, T. 1937a. A basic list of the land Mollusca of Australia. *Australian Zoologist* 8: 287-333.
- 1937b. A basic list of the land Mollusca of Australia. Part II. *Australian Zoologist* 9: 1-39.
1938. A basic list of the land Mollusca of Australia. Part III. *Australian Zoologist* 9: 83-124.
- KERSHAW, A.P. 1980. Long term changes in northeast Queensland rainforest. Pp. 32-38. In Wright, J., Mitchell, N. & Watling, P. (eds), 'Reef, rainforest, mangroves, man'. (Wildlife Preservation Society of Queensland: Brisbane).
1981. Quaternary vegetation and environments. Pp. 81-101. In Keast, A. (ed.), 'Ecological biogeography of Australia'. (W. Junk: The Hague).
- McMICHAEL, D.F. & IREDALE, T. 1959. The land and freshwater Mollusca of Australia. Pp. 224-245. In Keast, A., Crocker, R.L. & Christian, C.S. (eds), 'Biogeography and ecology in Australia'. (W. Junk: The Hague).
- MARTIN, H.A. 1981. The Tertiary flora. Pp. 391-406. In Keast, A. (ed.), 'Ecological biogeography of Australia'. (W. Junk: The Hague).
- OLLIER, C.D. 1982. The Great Escarpment of eastern Australia: tectonic and geomorphic significance. *Journal of the Geological Society of Australia* 29: 13-23.
- SIMPSON, R.D. & STANISIC, J. 1986. Faunal survey of New England. II. The distribution of gastropod molluscs. *Memoirs of the Queensland Museum* 22: 115-139.
- SMITH, B.J. 1984. Regional endemism of the south-eastern Australian land mollusc fauna. Pp. 178-188. In Solem, A. & Van Bruggen, A.C. (eds), 'World-wide snails. Biogeographical studies on non-marine Mollusca'. (E.J. Brill/Dr W. Backhuys: Leiden).
1992. Non-marine Mollusca. Pp. 1-405. In Houston, W.W.K. (ed.), 'Zoological Catalogue of Australia, Vol. 8'. (Australian Government Printing Service: Canberra).
- SMITH, B.J. & KERSHAW, R.C. 1979. 'Field guide to the non-marine molluscs of southeastern Australia'. (ANU Press: Canberra).
1981. 'Tasmanian land and freshwater molluscs. Fauna of Tasmania handbook No.5'. (University of Tasmania: Hobart).
- SOLEM, A. 1959. Zoogeography of the land and freshwater Mollusca of the New Hebrides. *Fiediana: Zoology* 43: 239-359.
1984. A world model of land snail diversity and abundance. Pp. 6-22. In Solem, A. & Van Bruggen, A.C. (eds), 'World-wide snails. Biogeographical studies on non-marine Mollusca'. (E.J. Brill/Dr W. Backhuys: Leiden).
1992. Camaenid land snails from southern and eastern South Australia excluding Kangaroo Island. *Records of the South Australian Museum, Monograph Series* 2: 1-338.
- SOLEM, A. & YOCHELSON, E.L. 1979. North American Palaeozoic land snails, with a summary of other Palaeozoic non marine snails. United States Geological Survey, Professional Paper 1072: 1-42.
- STANISIC, J. 1990. Systematics and biogeography of eastern Australian Charopidae (Mollusca, Pulmonata) from subtropical rainforests. *Memoirs of the Queensland Museum* 30: 1-241.
- STANTON, J.P. & MORGAN, G. 1977. The rapid selection and appraisal of key and endangered sites: the Queensland case study. University of New England School of Natural Resources, Report No. PR4, 17pp.+14appendices.
- WEBB, L.J. & TRACEY, J.G. 1981. Rainforests: patterns and change. Pp. 606-694. In Keast, A. (ed.), 'Ecological biogeography of Australia'. (W. Junk: The Hague).

## LOCAL DISTRIBUTION PATTERNS OF LAND SNAILS IN RELATION TO VEGETATION: IMPLICATIONS FOR RESERVE DESIGN.

ROBERT J. TAYLOR, ROBERT MESIBOV AND IVOR GROWNS

Taylor, R.J., Mesibov, R. & Grows, I. 1994 06 30: Local distribution patterns of land snails in relation to vegetation: Implications for reserve design. *Memoirs of the Queensland Museum* 36(1): 215-220. Brisbane. ISSN 0079- 8835.

Distribution patterns of land snails amongst forest communities were studied in a 500ha block of State forest in north-east Tasmania. Twelve species were found, four of which were represented by fewer than five individuals. Three of the eight common species were randomly distributed in relation to vegetation. Four others were most abundant in the wetter forest communities, close to drainage lines or adjacent slopes. The remaining common species was most frequently found in the driest community. Retention of streamside reserves when the area is logged would probably protect populations of all land snails. However, a more comprehensive system of reserves including all major vegetation communities would ensure protection of preferred habitat for all species. □ *Molluscs, land snails, distribution, vegetation community, reserve design, forestry.*

Robert J. Taylor, Forest Practices Unit, Forestry Commission, 30 Patrick Street, Hobart, Tasmania, Australia, 7000; Robert Mesibov, P. O. Box 700, Burnie, Tasmania, Australia 7320; Ivor Grows, Fisheries Research Institute, P O Box 21, Cronulla, N.S.W., Australia 2230; 30 July 1993.

Because invertebrates, many undescribed, are so diverse, a species-by-species approach to their conservation is totally impractical. Conservation agencies in Australia are now mostly aiming to adopt a strategy of creating reserves to ensure regional representation of vegetation communities. (Brown & Hickey, 1990; Commonwealth of Australia, 1992). It has been argued that a vegetation-based strategy will also cater for invertebrate conservation. Invertebrate assemblages are correlated with vegetation communities (Yen, 1987). However, distributions of many invertebrates are not influenced by changes in vegetation (Richardson, 1990) and species apparently restricted to one vegetation type may not occur throughout it (Hill & Michaelis, 1988; Cameron, 1992).

Mesibov (1993) studied litter invertebrates in north-western Tasmania in a 50 km<sup>2</sup> with rain-forest, wet eucalypt forest/woodland and tea-tree *Leptospermum lanigerum* scrub. He concluded that most species ranged across all vegetation types. Distribution patterns of several invertebrate groups across vegetation types at a much drier site in north-eastern Tasmania were here examined. Results for the land snails are presented. Snails were used as they were taxonomically well known, easily identified, numbers of species and densities expected were not excessive, and it was anticipated that they would be influenced by moisture gradients.

### STUDY AREA

The study was undertaken on State Forest in north-east Tasmania, in a 500ha block of sclerophyll forest to the north and south-west of Old Chum Dam (41°06'S, 148°03'E). Altitude varied from 100-250m on an underlying geology of Ordovician granite. Average annual rainfall was 978mm. Vegetation was studied by Duncan & Brown (1993) who utilised cover-abundance (Braun-Blanquet) floristic data to distinguish six forest communities:

#### (1) Blackwood gully forest

This forest was associated with gullies and creeklines, often forming a thin corridor along them. Sparse emergents (30m+) of *Eucalyptus obliqua* occurred over a dense secondary tree layer (20-30m) dominated by blackwood (*Acacia melanoxylon*). *Dicksonia antarctica*, *Olearia argophylla*, *Pomaderris apetala*, *Coprosma quadrifida* and *Bursaria spinosa* formed a dense medium to tall shrub-layer. The ground layer was dominated by ferns, including *Blechnum nudum*, *B. wattsii* and *Polystichum proliferum*. Low light levels reaching the forest floor precluded development of herbaceous species but bryophytes were common.

#### (2) Eucalypt gully woodland

This was adjacent to creeks and gullies where microclimate was slightly less humid and soil

moisture higher compared with sites supporting blackwood gully forest. The community comprised woodlands, grading into forest, with *E. obliqua* and occasional *E. viminalis* exceeding 30m. A medium to tall shrub layer and included eucalypts, *P. apetala*, *Melaleuca squarrosa* and *A. verticillata*. Trunked ferns (*Dicksonia*, *Todea* and *Cyathea*) were prominent. The ground layer was very dense compared with blackwood gully forest and was dominated by ferns with tall graminoids prominent on poorly drained sites. Herbaceous species were sparse and bryophytes less common than in blackwood gully forest.

### (3) Tall wet sclerophyll forest

This community occurred on well drained soils on south-facing middle to lower slopes. The upper stratum exceeded 30m and was dominated by *E. obliqua* with *E. viminalis* a minor species. The small tree and tall shrub layer was very sparse. The medium shrub layer (1-5m) was dense and mainly comprised *P. apetala*, *Monotoca glauca*, *A. verticillata*, *Zieria arborescens* and *Coprosma quadrifida*. A dense to very dense ground stratum, dominated by ferns (*Culcita dubia* and *Pteridium esculentum*), was present in some areas. Graminoids, grasses and herbs were sporadic in occurrence.

### (4) Damp sclerophyll forest

This community was widespread, mainly occupying slopes with south to east aspects. Soils were well drained and had moisture levels intermediate between wet and dry sclerophyll sites. *E. obliqua* and/or *E. amygdalina* were dominant with *E. viminalis* a minor species. The canopy was dense between 20 and 30m. The medium to tall shrub layer was very sparse and mainly comprised *A. terminalis*, *A. verticillata*, *Olearia lirata* and eucalypt regeneration. Vegetation below 1m was moderately dense with the relative abundance of sclerophyllous shrubs (e.g. *Pultenaea juniperina*, *Lomatia tinctoria*, *Leptospermum scoparium*) and bracken probably reflecting fire history. Graminoids, herbs and grasses were sparse but more prominent than in the wetter forest communities.

### (5) Scrub woodland

This community was strongly associated with basins and soakages with impeded drainage. *E. obliqua* and/or *E. amygdalina* were dominant. Trees were sparser, lower in height and poorer in form than those in surrounding forest. A dense to

very dense medium to tall shrub layer was dominated by *M. squarrosa* with *L. scoparium* and *A. verticillata* also prominent. The ground layer was often dense, being dominated by sedges, ferns and graminoids.

### (6) Heathy dry sclerophyll forest

This community was widespread in the study area, occupying well-drained middle and upper slopes subject to moderate drought stress. *E. amygdalina* was dominant with *E. obliqua* co-dominant or subdominant. The medium shrub layer was very sparse and the low shrub/ground layer was moderately dense being dominated by bracken (*P. esculentum*) and *L. scoparium* suggesting a history of frequent burning.

## METHODS

All 116 plots, each a 10m diameter circle, were located across the study area and stratified to sample the range of vegetation communities (blackwood gully forest, 14 plots; eucalypt gully woodland, 20; tall wet sclerophyll forest, 7; damp sclerophyll forest, 30; scrub woodland, 18; and heathy dry sclerophyll forest, 27). Over 27 days (15 May-23 June 1989), snails were searched (by B.M.) 60 minutes per plot. Areas examined were likely sheltering sites: bark scrolls, bases of ferns, leaf litter including litter built up at the base of trees, loose bark, moss, rotting wood, bases of graminoids (e.g. *Gahnia* and *Lomandra*), stones, tree ferns and woody litter. For each plot, variables recorded were: slope, aspect, overstorey age (mature or regrowth), plant species that contributed significantly to cover or provided shelter for snails for both the shrub layer (>1m) and the ground layer (if ground cover was dense plant species contributing significantly to this cover were given a rating of 2, rather than 1 for just their presence), a shade rating on a 1-3 scale and the type of shelters searched. Snails of many of Tasmania's terrestrial species are small (< 3 or 4mm in shell width or height). Hence, some smaller snails would have been missed on some plots. However, search effort was consistent over the plots. Hence, results from different plots should be comparable.

## NUMERICAL ANALYSIS

Ordination of snail data was carried out using semi-strong hybrid multidimensional scaling (SSH) in the PATN software package (Belbin, 1988). The Bray-Curtis coefficient was used as a



measure of dissimilarity between samples after standardising data by subtracting minimum abundance of a taxon and dividing by its range to reduce the weighting of abundant taxa. The number of dimensions required for the ordination was assessed by examining stress levels as a function of the number of dimensions from 10 random starts. The chosen number of dimensions was then used in 100 random starts and the one with the lowest stress used. The relationship between the ordination space and the abundances of snail species and the environmental variables were examined using the Principal Axis Correlation (PCC) procedure in the PATN program. The PCC procedure determines the best linear fit between ordination vectors and the variable under consideration (Belbin, 1988). The overall correlation coefficients determined by PCC were tested for statistical significance by using 100 Monte Carlo randomisations of the data set (Faith & Norris, 1989).

The distribution of snails in relation to vegetation communities was examined to see whether the observed patterns could be explained by random processes alone. The Group Definitions module in PATN was used for this analysis. The data for each species were randomised 100 times (Monte Carlo randomisations) and Cramer values calculated. These values are the between-group variance divided by the total variance and range from 0, where no discrimination between groups exist, to 1, where perfect inter-group discrimination occurs. If the Cramer value for the actual data was greater than 95 of the Cramer values from the randomised data sets the observed patterns were considered to represent a non-random distribution amongst vegetation communities. The significance of differences between frequencies of occurrence in different categories was determined using Chi-square tests.

## RESULTS

Twelve species of land snail were found on the study area (Table 1). Of the four species for which fewer than five individuals were located, three are very small (less than 3mm) and this may partly explain why few individuals were taken. The fourth species, *Thryasona diemenensis*, however, is conspicuous

and unlikely to have been missed. All four *Thryasona diemenensis* were found on one plot at the head of a gully in blackwood gully forest. *Miselaoma parvissima* and *Paralaoma caputspinulae* were found in heathy dry sclerophyll forest and one individual of *Roblinella gadensis* was found in each of eucalypt gully woodland and tall wet sclerophyll forest. These four species are not considered further due to their low frequencies of occurrence.

Two plots yielded no snails and were not included in the ordination. Four dimensions were required to describe the ordination of the plots on the basis of the abundance of snail species. *Caryodes dufresnii*, *Helicarion cuvieri* and *Tasmadelos nelsonensis* appeared to be randomly distributed amongst vegetation communities (Table 1 and Fig. 1). *Cystopelta petterdi* was most abundant in scrub woodland but occurred across the full range of vegetation types being lowest in abundance in blackwood gully forest. *Dentherona subrugosa* was most abundant in blackwood gully forest and occurred in low numbers in other wetter communities. *Elsothera ricei* occurred across all vegetation communities but was most abundant in the gully types. *Tasmaphena*

Species	Total No.	Cramer Value (Significance)	Vector coefficient r (Significance)
<b>CARYODIDAE</b>			
<i>Caryodes dufresnii</i>	50	0.21 (n.s.)	0.36 (n.s.)
<b>CHAROPIDAE</b>			
<i>Dentherona subrugosa</i>	32	0.66 (<0.05)	0.58 (<0.05)
<i>Elsothera ricei</i>	240	0.43 (<0.05)	0.62 (<0.05)
<i>Pernagera officieri</i>	118	0.36 (<0.05)	0.78 (<0.05)
<i>Thryasona diemenensis</i>	4	—	—
<i>Roblinella gadensis</i>	2	—	—
<b>CYSTOPELTIDAE</b>			
<i>Cystopelta petterdi</i>	290	0.42 (<0.05)	0.55 (<0.05)
<b>HELICARIONIDAE</b>			
<i>Helicarion cuvieri</i>	406	0.25 (n.s.)	0.82 (<0.05)
<b>RHYTIDIDAE</b>			
<i>Tasmadelos nelsonensis</i>	34	0.25 (n.s.)	0.78 (<0.05)
<i>Tasmaphena sinclairei</i>	13	0.32 (<0.05)	0.32 (n.s.)
<b>PUNCTIDAE</b>			
<i>Paralaoma caputspinulae</i>	2	—	—
<i>Miselaoma parvissima</i>	1	—	—

TABLE 1. Total number of each species of snail found in the study area along with an index of their discrimination between vegetation types (Cramer value) and the correlation coefficient of their vector of maximum correlation within the ordination space.

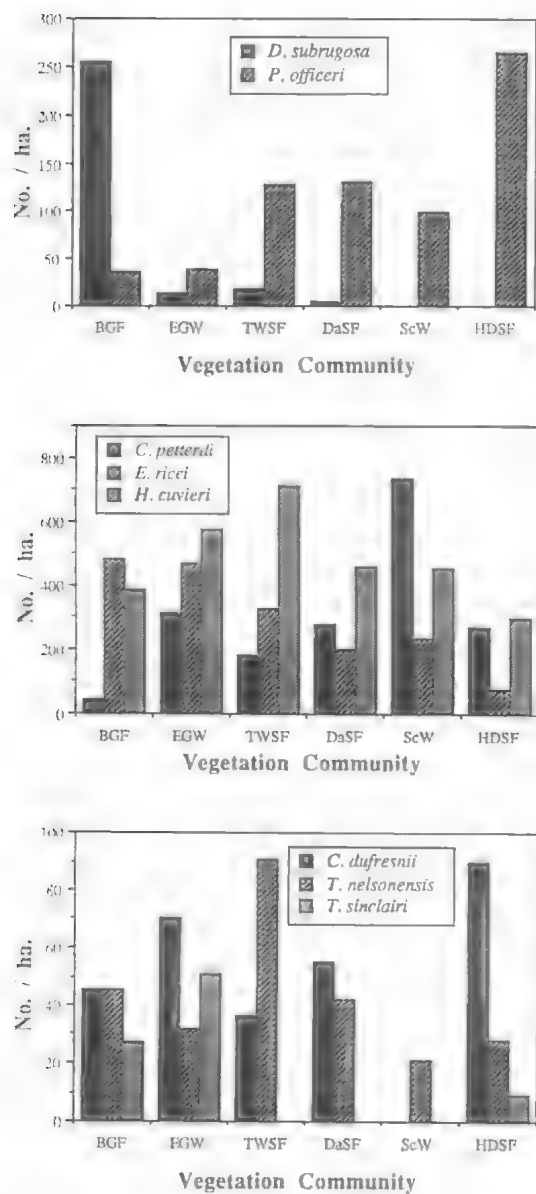


FIG. 1. Density of snail species (No./ ha.) in each vegetation community, BGF = blackwood gully forest, EGW = eucalypt gully woodland, TWSF = tall wet sclerophyll forest, DaSF = damp sclerophyll forest, ScW = scrub woodland and HDSF = heathy dry sclerophyll forest.

*sinclairi* was also most abundant in the gully communities. In contrast, *Pernagera officeri* was most abundant in the driest community, heathy dry sclerophyll forest.

These patterns are confirmed by the ordination (Table 1, Fig 2). *Dentherona subrugosa*, *El-*

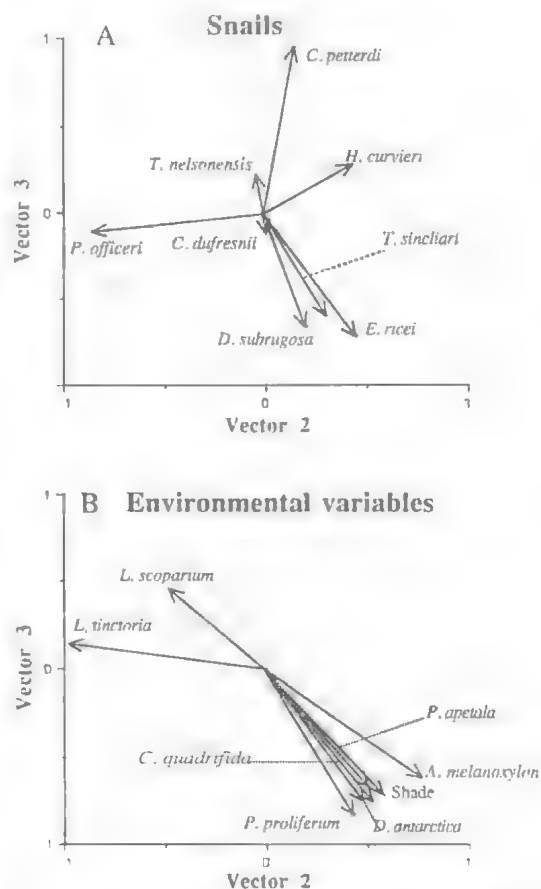


FIG. 2. Directions of vectors of maximum correlation with the ordination space for snail plots for each species (excluding 4 rare species) and for environmental variables showing similar directions to that of the snails. Vectors of similar length and direction indicate co-occurrence of snail species and/or environmental variable in the ordination space.

*sothera ricei* and *Tasmaphena sinclairi* had similar vectors of maximum correlation within the ordination space. However, the vector for *Tasmaphena sinclairi* was not significant, possibly due to the low abundance of this species. The vectors for environmental variables associated with the wetter vegetation communities (*D. antarctica*,  $r=0.49$ ; *P. apetala*,  $r=0.35$ ; *A. melanoxylen*,  $r=0.51$ ; *C. quadrifida*,  $r=0.40$ ; *P. proliferum*,  $r=0.44$ ; and shade,  $r=0.42$ ) had a similar direction to that of *Dentherona subrugosa*, *Elsothera ricei* and *Tasmaphena sinclairi*. For *Dentherona subrugosa* and *Elsothera ricei* the proportion of plots containing these snails variables was significantly greater (Chi-squared tests) where the above mentioned

plants were present (or where shading was greater) than for those plots where they were absent (or where shading was low). This was also the case for *Tasmaphena sinclairi* but sometimes not significantly so, probably due to fewer specimens. The vector for *Pernagera officieri* was similar to that for *L. tinctoria* ( $r=0.49$ ) and to a lesser extent *L. scoparium* ( $r=0.44$ ) (Fig. 2). Neither plant species occurred in the gully communities but ranged across other vegetation types. *L. scoparium* was the main low shrub species in the driest community, healthy dry sclerophyll forest. The proportion of plots containing *Pernagera officieri* was significantly greater where *L. tinctoria* and *L. scoparium* were present than for those plots where these plants were absent. *Caryodes dufresnii* was randomly distributed in the ordination space and in relation to vegetation communities. *Cystopelta petterdi* and *Helicarion cuvieri* had vectors in the ordination space that were dissimilar to all other species and to each other (Fig. 2) and these species' vectors did not closely relate to any vectors of the environmental variables. *Helicarion cuvieri* had the strongest vector of maximum correlation in the ordination space. However, its pattern of distribution appeared not to relate to vegetation. This was also the case for *Tasmadelos nelsonensis* which had the next strongest vector.

An examination of occurrence of snail species in different types of shelters (= microhabitat usage) reinforced the pattern indicated by vegetation. For example, *Dentherona subrugosa* was restricted to the wetter gullies and was significantly associated with tree fern (*D. antarctica*) heads as a shelter site. Tree ferns in turn were restricted to wetter gullies.

## DISCUSSION

Vegetation patterns in the study area are strongly related to topography via its influence on drainage (and thus soil moisture), soil fertility and protection from fire (Duncan & Brown, 1993). Better soils with a high organic content occur on the lower slopes and in gullies, and the shallower, more sandy soils occur on the ridges and steeper slopes. The distributions of three snails (*Caryodes dufresnii*, *H. cuvieri* and *Tasmadelos nelsonensis*) were not related to these vegetation patterns and all three were widespread across the study area. Distributions of other species were related to vegetation patterns but none were restricted to one vegetation type. The single site occurrence of *Thryasona diemenensis*, in black-

wood gully forest, is puzzling as it is very common in north-east Tasmania in a wide variety of wet habitats and even some dry areas (K. Bonham, pers. comm.).

Results here are similar to those of Mesibov (1993) on litter invertebrates in north-west Tasmania in that most species ranged across most of vegetation types. Both studies also found a minority of species were restricted to one or very few of the range of vegetation types examined. Mesibov's (1993) study also found distinct differences in densities of some species in different vegetation types, as our study did.

Because many invertebrates have restricted distributions, any generalised reserve system for invertebrates would need to include reservation of habitat at a localised level to supplement a regional vegetation based reserve system. Sampling of vegetation types and/or landforms should be undertaken comprehensively in such a localised reserve system as well as at a broader regional scale. Our study area occurs in State Forest. Until recently, the only systematic reservations at a local level in State Forests were streamside reserves, designed to protect water quality. These reserves extend from 20 to 40m either side of streams depending on stream and protect all streams with a catchment greater than 50ha (Forestry Commission, 1993). These reserves are thus biased towards wetter communities in gullies and areas of impeded drainage. Streamside reserves in the present study area would probably protect populations of most species, since most are widespread and/or have wetter forest types as their favoured habitats. However, *Pernagera officieri*, which reaches its highest densities in the driest vegetation type, would be poorly represented in such reserves. The preferred habitats for all species should be included within reserves. Retention of 100m-wide strips (referred to as wildlife habitat strips), which also include areas of slope and ridge and hence more comprehensively sample vegetation types at a local level, has therefore been introduced in Tasmanian State Forests (Taylor, 1991). Such measures should better provide for the conservation of invertebrates.

## ACKNOWLEDGEMENTS

Staff from the Fingal district of the Forestry Commission, particularly Mick Miller and Laurie Gregson, provided logistical support. Ron Kershaw assisted with snail identifications. Accommodation in the field was provided by Mr and Mrs

D. Jennings of Telita. The study was funded by the Forestry Commission of Tasmania and the Tasmanian Forest Ecology Research Fund.

#### LITERATURE CITED

- BELBIN, L. 1988. 'PATN reference manual' (CSIRO Division of Wildlife and Ecology: Canberra).
- BROWN, M. & HICKEY, J. 1990. Tasmanian forest — genes or wilderness? *Search* 21: 86-87.
- CAMERON, R.A.D. 1992. Land snail faunas of the Napier and Oscar Ranges, Western Australia; diversity, distribution and speciation. *Biological Journal of the Linnean Society* 45: 271-286.
- COMMONWEALTH OF AUSTRALIA 1992. 'National forest policy statement: A new focus for Australia's forests' (Commonwealth of Australia: Canberra).
- DUNCAN, F. & BROWN, M. 1993. Vegetation at Old Chum Dam in north-east Tasmania. Unpublished Report (Forestry Commission, Hobart).
- FAITH, D.P. & NORRIS, R.H. 1989. Correlation of environmental variables with patterns of distribution and abundance of common and rare freshwater macroinvertebrates. *Biological Conservation* 50: 77-98.
- FORESTRY COMMISSION 1993. 'Forest practices code'. (Forestry Commission of Tasmania: Hobart).
- HILL, L. & MICHAELIS, F.B. 1988. 'Conservation of insects and related wildlife'. Occasional Paper No. 13 (Australian National Parks and Wildlife Service: Canberra).
- HILL, M.O. 1979. 'Twinspan: A FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes' (Cornell University: Ithaca New York).
- MESIBOV, R. 1993. 'Species-level comparison of litter invertebrates from three vegetation types in northwest Tasmania'. Tasmanian NRCP Technical Report No. 13. Forestry Commission, Hobart and Department of Environment, Sport and Territories, Canberra.
- RICHARDSON, A. 1990. The implications of vegetation change for animals and their habitats. *Tasforests* 2: 173-178.
- TAYLOR, R. J. 1991. The role of retained strips for fauna conservation in production forests in Tasmania. Pp 265-270, In Lunney, D. (ed.), 'Conservation of Australia's Forest Fauna' (Royal Zoological Society of N.S.W.: Mossman).
- YEN, A.L. 1987. A preliminary assessment of the correlation between plant, vertebrate and Coleoptera communities in the Victorian mallee. Pp. 73-82, In Majer, J.D.(ed.) 'The Role of Invertebrates in Conservation and Biological Survey'. (W.A. Dept. of Conservation and Land Management: Perth).

## THE FORGOTTEN ARTHROPODS: FOLIAR MITES IN THE FOREST CANOPY

DAVID EVANS WALTER, DENNIS O'DOWD AND VANESSA BARNES

Walter, D.E., O'Dowd, D. and Barnes, V. 1994 06 30. The forgotten arthropods: foliar mites in the forest canopy. *Memoirs of the Queensland Museum* 36 (1): 221-226. Brisbane. ISSN 0079-8835.

Most studies of canopy invertebrates report few mites, yet mites were the most abundant arthropods in the upper canopies of rainforest trees and lianas around 3 forestry research towers in Queensland (means = 900 - 5,581 mites per m<sup>2</sup> of foliage). Within-site species diversity was high with 47 mite species being collected from just 46 leaves from the upper canopy (18-37m) in one tropical rainforest. Across-site diversity of leaf-inhabiting Parasitiformes (Phytoseiidae, Ascidae, Ologamasidae) was assessed using 2,818 slide-mounted specimens from eastern Australia. Of the 64 species identified, 30 were undescribed. A strong temperate to tropical increase in species richness was evident with little overlap (5%) in species between temperate and tropical forests. Foliar mites were a specialised fauna, generally absent from forest leaf litter. In temperate forests in Victoria, 28 species of oribatid mites were found on the leaves, stems, and trunk of musk daisy trees. Only 2 of the 18 species found on leaves and stems were also collected from soil-litter samples under the trees, indicating that the arboreal fauna is diverse, and distinct from that of the soil. □ *Acari, rainforest, canopy, biodiversity, Phytoseiidae, Ascidae, Oribatida.*

David Evans Walter, Department of Entomology and Centre for Tropical Pest Management, University of Queensland, St. Lucia, 4072, Australia; Dennis J. O'Dowd, and Vanessa Barnes, Department of Ecology & Evolutionary Biology, Monash University, Clayton, Victoria 3168, Australia; 30 July 1993.

Recent research in the canopies of tropical rainforests, relying primarily on chemical knock-down techniques, has discovered an amazing diversity of animal species, primarily insects. Mites, although they may be dominant in soils beneath the trees (Stork, 1991), appear to be uncommon in canopies, usually representing less than 7% of the total number of arthropods collected (Stork, 1988; Basset, 1991; Basset et al., 1992; Kitching et al., 1993). These studies leave the impression that mites are minor elements in the canopy fauna.

For the last three years, we have tried to develop an understanding of the interaction between foliar mites and leaf surface structures, especially leaf domatia (Walter, 1992; Walter & O'Dowd, 1992 a, b; Walter & Behan-Pelletier, 1993). Incidental to these studies, we have accumulated a large database on the abundance and diversity of foliar mites in Australian rainforests. Our results suggest that previous studies have grossly underestimated their abundance and diversity (Walter & O'Dowd, 1994). Rather than being relatively rare, arboreal mites are exceedingly abundant, by far the most abundant canopy arthropods. In the following paper, we support this statement with studies at three canopy towers in Queensland, Australia. We also present a preliminary analysis of species diversity at one tower, and discuss the

diversity of predatory foliar mites across sites and regions in eastern Australia. Finally, we show that foliar mites are a small subset of the arboreal fauna, and that the mites in the forest canopy are diverse and distinct from those in soil under trees.

### MATERIALS AND METHODS

#### ABUNDANCE & DIVERSITY OF FOLIAR MITES IN RAINFOREST CANOPIES

Three research towers in Queensland: Pine Creek near Gordonvale (16°59'S, 145°50'E), Curtain Fig near Atherton (17°16'S, 145°34'E), and Mick's Tower in the Green Mountains area adjacent to Lamington National Park (28°13'S, 153°07'E) were used to reach upper canopies (to 37m) of rainforest trees and lianas. From decks at various levels of each tower, extendable pole-pruners were used to clip small shoots; 1-5 leaves were removed from each shoot, placed in plastic bags, and refrigerated until processing. Processing consisted of scanning each leaf under a stereomicroscope using cool light, dissecting any structures (domatia, galls, webbing, exuviae, detritus, etc.) with a scalpel, and counting mites on both leaf surfaces. Representatives of all distinguishable mite taxa were collected into 70% alcohol with a small brush; excess mites were crushed to avoid double counting. Eriophyoid



Fig. 1. Species diversity of foliar Parasitiformes. Predatory parasitiform mites (Phytoseiidae, Ascidae, Ologamasidae) collected from the leaves of woody plants in Tropical, Subtropical, and Temperate Rainforests in eastern Australia showed a strong temperate to tropical gradient in species diversity. A total of 64 species was identified from 2,818 slide-mounted mites (see Table 3). Only two species occurred in both temperate and tropical rainforests (5%), but 22–23% of species were shared between adjacent climatic zones.

mites within galls were not counted (because they were too small, numerous, and difficult to extract), but any predatory or scavenging mites present in galls were collected. Mites were assigned to feeding guilds after Walter & O'Dowd (1994).

#### SITE & REGIONAL DIVERSITY OF FOLIAR PARASITIFORMES

Because of their importance in biological control, predatory parasitiform mites are relatively well known at the species level. We collected these mites from 13,266 leaves from 193 species of trees, shrubs, and lianas between 17 November 1990 and 1 May 1993. Except in Victoria, only rainforest vegetation was sampled, i.e. fire-protected or fire-resistant forests with closed-

canopies composed of broad-leaved, evergreen vegetation not dominated by species of *Eucalyptus* or *Acacia* (Gell & Mercer, 1992). Tropical rainforest sites in North Queensland included Cape Tribulation (Daintree, Mossman), Cairns (Gordonvale to Mission Beach); Mt. Lewis, the Atherton tablelands, and Mt. Spec. Subtropical rainforest sites included SE Queensland (Fraser Island to Maroochydore), the North Coast of New South Wales (Kingsport to Myall Lakes); the Border Ranges (including Mt. Waring and the Nightcap Mts.), and the Great Dividing Range (Washpool National Park to Barrington Tops). Temperate rainforest sites included the South Coast (southcoast of N.S.W. and East Gippsland), Wilson's Promontory; the Great Dividing Range, Victorian Central Highlands, Otway Ranges, and Tasmania (Fig. 1). In Victoria, four sclerophyll forests and a mangrove site were also sampled. Leaf areas were measured on an image analyser (Image 3.0, Monash University, Clayton, Australia). Species identifications are based on mites cleared in Nesbitt's solution and mounted in Hoyer's medium on glass slides (Krantz, 1986).

#### DISTRIBUTION OF ORIBATID MITES ON MUSKY DAISY

Oribatida, mites that feed on fungi and scavenge detritus, and have strongly sclerotised adults that are easily sorted to morphospecies, were used to assess species distributions within a tree. Four strips of bark (each 16 cm<sup>2</sup>), 6 segments of stem (each c. 15 cm long), and 8 leaves were randomly selected from each of 11 musk daisy trees (10 *Olearia argophylla*, one *O. lirata*) growing in warm to cold temperate rainforests in south-central Victoria. In addition, 4 cores of leaf litter (each 50 cm<sup>2</sup> and 2 cm deep) were randomly taken under the canopy of the trees about a half metre from the trunk. Samples were stored in plastic bags, refrigerated, and examined within 48 hours of collection. Bark, stem, and leaf samples were scanned under a stereomicroscope and mites collected as above. Soil samples were extracted using Tullgren funnels (60 watt light bulbs) over 70% ethanol for three days.

#### RESULTS

##### ABUNDANCE & DIVERSITY OF FOLIAR MITES IN RAINFOREST CANOPIES

Upper canopy leaves were sampled from 5 trees species in lowland tropical rainforest near Pine Creek, 4 tree species in montane tropical rainforest at Curtain Fig, and 3 tree species and a furry

	Leaves	Predators	Herbivores	Scavengers	Total mites	foliage (m <sup>2</sup> )	Mites / m <sup>2</sup>
<b>Curtain Fig Tower</b>							
<i>Aleurites moluccana</i>	6	11	0	7	18	0.084	214
<i>Argyrodendron peralatum</i>	20	36	0	241	277	0.352	787
<i>Diploglottis diphylostegia</i>	15	481	705	245	1431	1.082	1323
<i>Toona australis</i>	5	44	6	94	144	0.559	258
Total Examined	46	572	711	587	1870	2.077	
<b>Pine Creek Tower</b>							
<i>Acacia aulacocarpa</i>	45	2	0	6	8	0.069	117
<i>Beilschmedia bancroftii</i>	50	1	76	2	79	0.083	951
<i>Flindersia pimentaliana</i>	20	6	0	16	22	0.296	74
<i>Polyalthia</i> sp.	40	17	0	25	42	0.060	701
<i>Sarcopteryx stipata</i>	5	26	391	25	440	0.048	9203
Total Examined	160	52	467	72	591	0.556	
<b>Mick's Tower</b>							
<i>Euodia micrococca</i>	44	12	5	2	19	0.147	130
<i>Parsonsia fulva</i>	35	304	598	1859	2761	0.258	10684
<i>Randia benthamiana</i>	50	87	1	458	546	0.142	3856
<i>Synoum glandulosum</i>	35	217	6	1052	1275	0.301	4238
Total Examined	164	648	594	3485	4727	0.847	

Table 1. Foliar mite densities. Forestry research towers near Atherton (Curtain Fig), Gordonvale (Pine Creek), and Lamington National Park (Mick's Tower) were used to obtain leaves from the canopies of rainforest trees. Each leaf was examined under a stereomicroscope, mites were identified to family or generic level, counted, and assigned to a feeding guild (Walter & O'Dowd, 1993). Leaf areas were then measured with an image analysis scanner.

silkpod liana (*Parsonsia fulva* Blake) in montane subtropical rainforest at the Green Mountains. The leaves of every plant species sampled carried mites, and densities ranged from a low of 74 per m<sup>2</sup> on the leaves of a Queensland ash (*Flindersia pimentaliana* Muell.) at Pine Creek to a high of 10,684 per m<sup>2</sup> on leaves of the liana furry silkpod (Table 1). In total, 7,188 mites were collected from the 3.48 m<sup>2</sup> of foliage sampled with average densities of 1,063 mites per m<sup>2</sup> at Pine Creek, 900 per m<sup>2</sup> at Curtain Fig, and 5,581 per m<sup>2</sup> at the Green Mountains.

The species composition of the foliar mite fauna sampled at Curtain Fig Tower was investigated in detail. Five leaf samples taken at each of 4 heights (22–37 m) in the canopy of a red tulip oak (*Argyrodendron peralatum* [Bail.] Edlin ex Boas) contained 5 species of predatory mites and 14 species of scavengers. Similar samples taken at 3 heights (18–26 m) in an adjacent brown tamarind (*Diploglottis diphylostegia* [F. Muell.] Bail.) contained 2 species of herbivorous mites, 9 species of predators, and 13 species of scavengers. However, only 1 predatory and 3 scavenging species were shared between the 2

trees (10%). Single samples near the tops (36 and 26 m, respectively) of a candlenut (*Aleurites moluccana* [L.] Willd.) and a red cedar (*Toona australis* [F. Muell.] Harms) yielded an additional 8 species (2 herbivores, 4 predators, 2 scavengers), such that the total sample of 46 upper canopy leaves contained 47 species of mites. Additional understory samples of 15 red tulip oak leaves contained 6 mite species not collected from any of the upper canopy samples (Table 2).

**Site and Regional Diversity of Foliar Parasitiformes.** A total of 64 species of parasitiform mites were identified from the 2,818 slide-mounted mites examined (Table 3). All but one species (Ologamasidae) belonged to two closely related families, Phytoseiidae and Ascidae. A strong positive temperate to tropical species diversity gradient was apparent (Fig. 1), and there was little species overlap between the three rainforest climate types. Only two (*Typhlodromus dachanti* Collyer, *Typhlodromus novaezealandiae* Collyer) of the 38 species found in tropical rainforests were also present in temperate rainforests. Tropical and subtropical



	Height Above Ground (m)					
	37	30	26	22	5	4
<b>Predators</b>						
<i>Lasioseius</i> sp. c	+					
<i>Odellidae</i> sp. 1	+					
<i>Neocunaxoides</i> sp. 1		+	+	+		
<i>Amblyseius</i> sp. d		+	+	+	+	+
<i>Iphiseius</i> sp. 1			+			
<i>Rubroscirus</i> sp. 1						+
<i>Lasioseius</i> sp. z						+
<i>Zetzellia</i> sp.						+
<b>Scavenger / Microbivores</b>						
<i>Symbiobates</i> sp.	+	+	+	+		
<i>Scapheremaeus</i> sp. L		+	+			
<i>Scapheremaeus</i> sp. G			+			
<i>Oribatuloidea</i> sp. 1			+			
<i>Tydeidae</i> sp. 2			+			
<i>Scapheremaeus</i> sp. J	+			+		
<i>Oribatuloidea</i> sp. 2	+			+		
<i>Tydeidae</i> sp. o		+		+		
<i>Tarsonemidae</i> sp. s				+		
<i>Tarsonemidae</i> sp. y				+		
<i>Tydeidae</i> sp. f				+		
<i>Scapheremaeus</i> sp. s	+	+			+	+
<i>Daidalotarsonemus</i> sp.	+	+	+	+		+
<i>Tarsonemidae</i> sp. g		+	+	+	+	+
<i>Tarsonemidae</i> sp. w			+		+	+
<i>Scapheremaeus</i> sp. P			+	+	+	+
<i>Eupodidae</i> sp. 1			+	+	+	
<i>Triophyteinae</i> sp.				+	+	
<i>Malaconothridae</i> sp. 1					+	+
<i>Tydeidae</i> sp. f2						+
Total Mite Species	7	8	13	14	9	11

Table 2. Within-tree distribution of mite species. At each of 4 levels (22-37 m) in a large red tulip oak (*Argyrodendron peralatum*) growing beside Curtain Fig Tower near Atherton in north Queensland, mite species were identified from 5 leaf samples. Additional samples were taken at 5 m (10 leaves) and 4 m (5 leaves) in two understory red tulip oaks. A total of 28 species of mites was found on 35 leaves sampled, with each level producing more species of predatory or scavenging mites. No herbivorous mites were discovered.

collections contained 56 species of which 13 (23%) were shared, and temperate and subtropical collections produced 36 species of which 8 (22%) occurred in both forest types.

#### DISTRIBUTION OF ORIBATID MITES ON MUSKY DAISY

A total of 2,116 oribatid mites were collected from on and under musk daisy trees in Victoria (Table 4). Twenty-eight species of oribatid mites were found on the leaves, stems, and trunks (6-17 species per site). All but one leaf-inhabitant was also collected from small stems, but none were found on the trunks of the trees, and only one foliar species (*Mycozetes* sp.) occurred in the leaf litter samples. Two species found on small stems (including *Mycozetes* sp.) and 5 additional species from the trunk were also present in litter samples. Leaf-litter and surface soil beneath the trees harboured over 40 species of oribatid mites.

#### DISCUSSION

Rainforest canopies are covered in mites, many species and uncountable numbers. This richness of animals must have consequences for the canopy system, especially those resulting from the feeding of the abundant predatory and scavenging mites. The prevalence of plant species with leaf domatia, and their predominant use by these feeding guilds, must have evolved over long periods of time (O'Dowd et al., 1991), and strongly supports the assumption of a functional relationship between arboreal mites and rainforest trees (O'Dowd & Willson, 1989; Walter & O'Dowd, 1992 a, b, 1994).

Our studies barely scratch the surface of the canopy mite assemblage, but they do show that previous studies have generally neglected or missed these animals. For example, Kitching et al. (1993) reported mites to comprise 1,503 of the 22,984 arthropods collected (6.5%) from subtropical rainforest canopies in the Green Mts. adjacent to Lamington National Park in Queensland. Kitching et al. (1993) used a chemical knockdown technique to sample many cubic metres of the canopy, and collected the resulting rain of arthropods on 90 m<sup>2</sup> of funnels (10 funnels of 0.5 m<sup>2</sup> x 2 samples x 9 sites). They found 17 mites per m<sup>2</sup> of funnel, the highest density of mites reported in any study from subtropical or tropical rainforests (Walter & O'Dowd, 1994). Yet our study, at the same site, indicated that the 3 trees and the liana that we sampled averaged 5,581 mites per m<sup>2</sup> of foliage. Clearly, chemical knockdown techniques provide only a minimum estimate of the true abundance and diversity of arthropods in rainforest canopies.

Our results assessing the oribatid mites associated with musk daisy show that arboreal species are rare in the soil beneath the trees, and

	Ascidae			Phytoseiidae							Caliphis Ologamasidae	Total Species	Mites Examined
	<i>Aceria</i>	<i>Lasioseius</i>	<i>Arctoseius</i>	<i>Amblyseius</i>	<i>Erioseius</i>	<i>Typhloseius</i>	<i>Okarieus</i>	<i>Paraphytoseius</i>	<i>Phytoseius</i>	<i>Typhlodromus</i>			
Tropical Rainforest	6	6	0	12	1	1	1	2	3	6	0	38	896
Subtropical Rainforest	2	1	1	11	2	1	0	1	6	7	0	32	830
Temperate Rainforest	0	0	0	1	1	0	0	0	3	6	1	12	755
Sclerophyll Forest	1	0	0	1	1	0	0	0	3	6	0	12	337
Total Species	6	6	1	20	4	1	1	2	9	13	1	64	2818

Table 3. Species of Foliar Parasitiformes by Genus. Slide-mounted parasitiform mites (Ascidae, Phytoseiidae, Ologamasidae) collected from leaves of 193 species of trees and lianas from Tasmania to the Cape Tribulation Region in eastern Australia (see Fig. 1) were identified to species. Of 64 species identified, at least 30 (47%) are undescribed.

that the foliar fauna is a small subset of the total arboreal mite assemblage (6 of 28 species in this study). Surviving on a leaf surface, especially one like musk daisy leaves with a slick surface of appressed hairs and without domatia or other refugia, must be especially difficult for minute animals. Success on such a bleak habitat, exposed to alternate periods of bucketing rain and intense insolation, must require specialised physiological, morphological and behavioural adaptations not needed by mites in more cryptic habitats like soil and bark. However, a number of oribatid mite taxa are leaf specialists (Walter & Behan-Pelletier, 1993). This is also true for foliar Parasitiformes. Only 2 (*Arctoseius semiscissus* [Berlese], Ologamasidae sp. 1) of the 64 species we collected also occur in soil, and it seems likely that numerous other species inhabit the stems, trunk, epiphytes, and hanging humus that occur on tropical rainforest trees.

The case for biodiversity being centred in invertebrates in rainforest canopies is well established, but the portion mites represent in this cornucopia is unknown. Although foliar mite species are but a small fragment of the total canopy fauna, there do seem to be numerous species. Predatory mites showed little overlap within or between regions (Fig. 1), at Curtain Fig few predatory or scavenging mite species were shared between adjacent trees, and even within a tree, more species were discovered with each new level sampled (Table 2). How is the high diversity of generalised predators and scavengers main-

tained? No one knows, and we are unlikely to answer this question for mites or any other diverse group of animals if we continue to rely on solely on chemical knockdown techniques.

#### ACKNOWLEDGEMENTS

We thank Peter O'Reilly, O'Reilly's Rainforest Rest, for his kindness and help during our research, and the people at the Tropical Research Centre, CSIRO, Atherton for their help. Our research was often aided by courteous and knowledgeable rangers and foresters throughout eastern Australia, and we thank them and the Department of Parks, Wildlife and Heritage, Tasmania, the Department of Conservation and Environment, Victoria, the National Parks and Wildlife Service and the State Forests of New South Wales, the Queensland Forestry Commission, and the Queensland National Parks and Wildlife Service for their collection permits. This research was supported by the Australian Research Council.

#### LITERATURE CITED

- BASSET, Y. 1991. The taxonomic composition of the arthropod fauna associated with an Australian rainforest tree. *Australian Journal of Zoology* 39: 171-190.
- BASSET, Y., ABERLENC, H., & DELVARE, G. 1992. Abundance and stratification of foliage arthropods in a lowland rain forest of Cameroon. *Ecological Entomology* 17: 310-318.

	Total Mites collected	Densities (/m <sup>2</sup> )	Total Species	Percent Species Overlap		
				Leaves	Stems	Trunk
Leaves	436	1343	6			
Stems	253	26	17	Stem	28	-
Trunk	31	440	14	Trunk	0	15
Litter	1396	6350	40	Litter	2	4
						10

Table 4. Arboreal Oribatid mite fauna. Oribatid mites were collected from leaves (88), small stems (9.9 m), and bark (704 cm<sup>2</sup>) from main trunk of 11 musk daisy trees (*Olearia* spp.) growing in rainforests in Victoria. Mites were also extracted from cores of leaf litter and upper 2 cm of soil taken under each tree. The arboreal fauna was distinct from that in leaf litter. Of 28 species found on trees, only 7 (primarily from trunks) also occurred in leaf litter under trees.

- GELL, P. & MERCER, D. 1992. 'Victoria's Rainforests: Perspective's On Definition, Classification and Management' (Monash Publications in Geography No. 41: Clayton, Victoria).
- KITCHING, R.L., BERGELSON, J.M., LOWMAN, M.D., MCINTYRE, S. & CARRUTHERS, G. 1993. The biodiversity of arthropods from Australian rainforest canopies: General introduction, methods, sites and ordinal results. *Australian Journal of Ecology* 18: 181-191.
- KRANTZ, G. W. 1986. 'A Manual of Acarology'. 1986. (Oregon State University Book Stores: Corvallis, Oregon).
- O'DOWD, D.J., BREW, C.R., CHRISTOPHEL, D.C., & NORTON, R.A. 1991. Mite-plant associations from the Eocene of southern Australia. *Science* 252: 99-101.
- O'DOWD, D.J. & WILLSON, M.F. 1989. Leaf domatia and mites on Australasian plants: Ecological and evolutionary implications. *Biological Journal of the Linnean Society* 37: 191-236.
- STORK, N.E. 1988. Insect diversity: facts, fiction and speculation. *Biological Journal of the Linnean Society* 35: 321-337.
1991. The composition of the arthropod fauna of Bornean lowland rain forest trees. *Journal of Tropical Ecology* 7: 161-180.
- WALTER, D.E. 1992. Leaf surface structure and the distribution of *Phytoseius* mites (Acarina: Phytoseiidae) in south-east Australian forests. *Australian Journal of Zoology* 40: 593-603.
- WALTER, D.E. & BEHAN-PELLETIER, V. 1993. Systematics and ecology of *Adhaesozetes polyphyllos*, sp. nov. (Acari: Oribatida: Licneremaeoidea) leaf-inhabiting mites from Australian rainforests. *Canadian Journal of Zoology* 71:1024-1040.
- WALTER, D.E. & O'DOWD, D.J. 1992a. Leaves with domatia have more mites. *Ecology* 73: 1514-1518.
- 1992b. Leaf morphology and predators : Effect of leaf domatia on the abundance of predatory mites (Acari : Phytoseiidae). *Environmental Entomology* 21: 478-484.
1994. Life on the forest phylloplane: Hairs, little houses, and myriad mites. Pp. xx-xx. In Lowman, M. & Nadkarni, N. (eds), 'Forest canopies - a review of research on this biological frontier.' (Academic Press: New York) (in press).

## PROSPECTS OF CAPTIVE BREEDING FOR THREATENED AUSTRALIAN NON-MARINE INVERTEBRATES

ALAN L. YEN

Yen, A.L. 1994 06 30: Prospects of captive breeding for threatened Australian non-marine invertebrates. *Memoirs of the Queensland Museum* 36(1): 227-230. Brisbane. ISSN 0079-8835.

Apparent success of captive breeding in conservation of threatened vertebrates suggests that it is also an option for threatened invertebrates. Captive breeding is misunderstood, including its use in conservation and commercial programmes and the distinction between maintenance and breeding in captivity. It is not a panacea for conservation of threatened invertebrates but part of a recovery plan of threatened species. Uncontrolled attempts at captive breeding and subsequent release into the wild should be prevented. Hence, a protocol for captive breeding of threatened non-marine Australian invertebrates is proposed. □ *Captive breeding, invertebrate conservation, Australia.*

Alan L. Yen, Invertebrate Survey Department, Museum of Victoria, 71 Victoria Crescent, Abbotsford, Victoria, Australia 3067; 28 July 1993.

Wildlife conservation can be in situ and/or ex situ. Captive breeding of vertebrates dominates the latter. It forms a major and often successful component of recovery plans for threatened species of vertebrates (Cohn, 1988).

Captive breeding is controversial because of the high costs of saving few species. Its critics argue that funds would be better spent saving species in their natural habitats. It should not be seen as a solution to save all threatened species but should be used in 'flagship' programmes to highlight threats both to animals and their habitats.

Its 'success' in vertebrates suggests its value with threatened invertebrates whose generally high rates of immature mortality can be reduced by the method. These assumptions are examined for captive breeding of threatened Australian non-marine invertebrates and if it becomes an integral part of their conservation strategies, issues need to be resolved.

### SCOPE

The importance of captive breeding in vertebrate conservation is recognised by the IUCN, which has a Species Survival Commission Captive Breeding Specialist Group (SSC-CBSG). In 1987, the IUCN released a policy statement that the survival of many species, especially those in much reduced and fragmented habitats, requires establishment of self-sustaining captive populations and other supportive intervention (IUCN SSC-CBSG, 1987).

The SSC-CBSG has focused on vertebrates but, in 1990, an Invertebrate Group was formed, finally

heeding earlier pleas (Morton, 1983). Objectives of this Group include:

1. Communication within regions of groups involved in invertebrate captive management and conservation, with other SSC Invertebrate Specialist Groups and with other relevant organisations;
2. Education to promote invertebrate conservation and roles of live invertebrates in exhibitions and use of invertebrates in education;
3. Research into captive breeding technology; and
4. Conservation of invertebrates, promotion of habitat protection and in situ conservation (Hughes & Bennett, 1991).

Captive breeding consists of the breeding programme and end-use of captive bred material. The term is associated with breeding threatened species for conservation. Other activities that need captive breeding are overlooked. Its aims are:

1. Conservation of threatened species;
2. Scientific research; (a), life history studies and (b), Biomonitoring agents;
3. Commerce: (a), Specimens for invertebrate zoos; (b), trade of live and dead specimens for collectors; (c), specimens for teaching purposes; (d), invertebrate cultures as vertebrate food; (e), commercial production—aquaculture, silk, etc., and (f), breeding of biological control agents.

Commercial ventures, especially 3(d) - 3(f), are generally run on a larger scale. Maintaining specimens and breeding them in captivity are different. Maintenance is removal of specimens from the wild and their display with no serious attempt to breed them. Captive breeding is the initial removal of specimens from the wild and rearing in captivity.

### PROSPECTS FOR CAPTIVE BREEDING OF THREATENED AUSTRALIAN INVERTEBRATES

Of 269 programmes officially recognised by the American Association of Zoological Parks and Aquariums, only one involves an invertebrate (Hughes & Bennett, 1991). This is international programme maintains species of *Partula* snails, now extinct in the wild, for possible release back into Polynesia when conditions are suitable (Tonge & Bloxam, 1991). Other programmes include the Red-kneed tarantula, *Euathlus smithii*, although there has been no attempt at re-introduction (Clarke, 1991); the Italian ground beetle, *Chrysocarabus olympiae*, for which the success of re-introduction is still unclear (Malausa & Drescher, 1991); and many attempts for species of British butterflies (Thomas, 1989). However, there is still very little co-ordination, at either the regional or international level, of captive breeding of species already kept in culture (Hughes & Bennett, 1991).

No captive bred threatened Australian invertebrates are known. Several species have been considered and an initial management plan for the Eltham Copper butterfly, *Paralucia pyrodiscus lucida* (Vaughan, 1988) has been proposed.

Feasibility of captive breeding for threatened Australian invertebrates is examined using the list of Hill & Michaelis (1988) as an exercise. However, those taxa are here placed into broad habitat groups and trophic levels (Table 1). The habitat categories are very broad and artificial but, in terms of captive breeding, over 25% of the taxa have habitat requirements that may be technically difficult to simulate in an ex situ situation (namely aquatic habitats and caves). Some species may have aquatic immature stages and adults that disperse and mate in terrestrial habitats. Although artificial streams and simulated cave environments are achievable in the laboratory, there is still a gap between maintenance and breeding. At the trophic level, the breakdown is given in Table 1. Theoretically, predators and herbivores should be easier to breed unless they have some special habitat requirements, specialised dietary requirements or have some biotic interactions with other species. For example, over half of the herbivores are butterflies, and this suggests that the only issue is the host plant requirements of the herbivore. However, many of these herbivores are intimately associated with ants. This adds another dimension to captive breeding. For other species, such

Table 1. Number of species or subspecies of threatened invertebrates grouped by their 'habitat' and 'trophic level' requirements (from Hill & Michaelis, 1988)

'TROPIC LEVEL'	'HABITAT'				
	aquatic	cave	ground	vegetation	%
Predator	7	1	9		20.2
Herbivore				48	57.2
Scavenger	1	4		2	8.3
Omnivore	8	2		1	13.1
Parasitoid				1	1.2
%	19.1	8.3	10.7	61.9	

as the ant *Nothomyrmecia*, sociality may be a barrier to successful captive breeding.

Some technical issues associated with proposed captive breeding programmes follow. In 1992, the Victorian Department of Conservation and Natural Resources suggested that fuel reduction burning was needed to maintain the habitat of the Eltham Copper Butterfly and that butterflies should be collected and bred in captivity in case the burn adversely affected their populations. The Melbourne Zoo Butterfly House was nominated. However, the captive breeding programme has been temporarily suspended because of (1) uncertainty about breeding the dwarf form of the *Bursaria spinosa* host plant of the Eltham Copper butterfly; (2) lack of data on maintaining the *Notoncus* ants associated with it; (3) question of where and how much source material could be collected; (4) lack of information about the butterfly's genetics; and (5) the Butterfly House was set up for tropical butterflies not for temperate species, like the Eltham Copper.

Captive breeding was also a suggested conservation option for the Giant Gippsland Earthworm, *Megascolides australis*. However, much early biological data on *M. australis* were incorrect (Van Praagh et al., 1989) and its slow developmental rate, apparent longevity (Van Praagh, 1992), and its reliance on an intact permanent three-dimensional burrow system (Kretzschmar & Aries, 1992) make it difficult to be captive bred.

Few species listed in Hill & Michaelis (1988) could be successfully captive bred. Biological data for many are not known and habitat requirements may be difficult to simulate in the laboratory. Issues arising from any captive breeding proposal for threatened invertebrates could be resolved more easily if a protocol for captive breeding is developed and accepted (Lees, 1989).

Such a protocol should not be used in isolation but has to be closely linked with protocols for translocation and reintroduction. These protocols prevent events like that in the United Kingdom where an estimated 1,000 or more reintroductions of butterflies have been attempted. In some attempts, wild stock was translocated while in others captive bred stock were released. These attempts were poorly documented and in the past there was little control over the efforts (Thomas, 1989). This must not occur in Australia where most invertebrates are poorly documented and uncontrolled introductions may have unforeseen ecological consequences. Translocation of captive bred freshwater crayfish already occurs (Horwitz, 1990).

### PROTOCOL

For threatened species, a recovery plan that incorporates all possible conservation strategies is needed. The primary aim of any recovery plan should be the protection of species in their original habitat through the control of threatening processes. Captive breeding should only be considered as part of an overall recovery plan and as the last option when the species cannot survive in its original habitat or as a means of obtaining basic biological information required to implement a recovery plan. If it is to be considered, then two primary issues need to be assessed: potential for its success and for reintroduction success. Reintroduction is a major undertaking in itself and will not be considered further here because it requires its own protocol (New, *in press*).

Such a protocol could also include a priority scoring system that weights each technical issue with a score (1 = known, no adverse effects, or possible; 0 = not known, some adverse effects, or not possible). The sum of those scores may indicate the feasibility of captive breeding of any particular taxon.

1. What will be captive bred? Is the proposed taxon a species or subspecies?
2. What will happen to captive bred specimens? Will they be reintroduced into an already occupied habitat or into a former one? What effects will reintroduction have on other taxa? What life history stage should be used for reintroduction? Is introduction to a new habitat the only option? Is there any commercial potential for captive bred material?
3. Biology. Is there adequate knowledge of the taxon's biology — life history stages, developmental periods, longevity, feeding habits, habitat requirements and breeding behaviour? Do immature and adult habitats differ? Is the taxon social? Does the

taxon have any special associations or interactions with plants, ants or otherwise?

4. Distribution. How well known is the taxon's distribution? Has its distribution been adequately surveyed? Are all populations known for consideration as potential sources of breeding stock?
5. Genetics. This is a very difficult area because genetic data of most invertebrates are unknown. Is there information on the taxon's intraspecific genetic variation (Morton, 1991b)? What measures can prevent possible inbreeding depression, minimise genetic adaptation to captivity and make the captive environment like the wild? This latter aspect may conflict with other technical aspects that improve the success of captive breeding programmes, e.g. use of artificial diets, controlled environments to maximise breeding success, and exclusion of natural enemies.
6. What is the source population and what effect will removal have on the taxon's survival?
7. If material of a taxon in decline is to be removed from the wild, when should this occur in relation to that trend?
8. Is there sufficient technical knowledge for successful breeding of the taxon in captivity?
9. Are there adequate facilities for captive breeding? This requires adequate infrastructure support for successful rearing, e.g., controlled rearing rooms, greenhouse facilities and staff. Are the facilities suitable? For example, calls for captive breeding of butterflies in the United Kingdom revolve around using facilities of many butterfly farms (Lees, 1989). Are quarantine procedures adequate to prevent introduction of diseases or unwanted species of invertebrates? What are the consequences of captive bred specimens escaping and breeding in the wild? Are measures adequate for the control of bacterial, fungal, protozoan and viral infection (Rivers, 1990)?
10. What are the potential and real benefits for other threatened taxa?

### DISCUSSION

At this stage, prospects of captive breeding of threatened Australian invertebrates may appear to be low but its potential role in invertebrate conservation should not be underestimated because:

1. Some species may need captive breeding;
2. Captive bred flagship species could be used effectively to highlight the need for invertebrate (and habitat) conservation;
3. It is an important source of biological data that are essential for threatened species conservation (Lees, 1989); and
4. Captive breeding technology provides benefits like advances in equipment and techniques (Morton, 1991a), including research into the use of artificial



diets and in mass culturing technology required for aquaculture, production of biological control agents, etc.

Many invertebrate species can be maintained and bred in a relatively small space. Their true biological diversity could be displayed – a major advantage over vertebrates.

Many potential 'cute and chitinous' invertebrates can be used as flagship taxa for the group's conservation. However, we are failing in our duty to that issue if we do not fully use their diversity as part of a broad, integrated conservation agenda that involves a public awareness educational programme, live exhibits, encouraging the use of local natural history to stimulate interest in conservation (Yen, 1993) and captive breeding of selected threatened invertebrates. It will be impossible to apply single species conservation strategies to most invertebrate species. A broader agenda will be more useful to conserve most invertebrate species because it has greater potential to convey their need for conservation. Captive breeding of selected flagship taxa could be a powerful part of this agenda. To this end, a protocol for captive breeding of threatened invertebrates is a small but important step.

#### ACKNOWLEDGEMENTS

I wish to thank Dr Tim New for making useful comments on an earlier draft of this manuscript.

#### LITERATURE CITED

- CLARKE, D. 1991. Captive breeding programme for the Red-kneed bird-eating spider *Euwathlus smithii* at London Zoo. *International Zoo Yearbook* 30:68-75.
- COHN, J.P. 1988. Captive breeding for conservation. *BioScience* 38:312-316.
- HILL, L. & MICHAELIS, F.B. 1988. Conservation of insects and related wildlife. Australian National Parks and Wildlife Service Occasional Paper No. 13, 40 pp.
- HORWITZ, P. 1990. The translocation of freshwater crayfish in Australia: potential impact, the need for control and global relevance. *Biological Conservation* 54:291-305.
- HUGHES, D.G. & BENNETT, P.M. 1991. Captive breeding and the conservation of invertebrates. *International Zoo Yearbook* 30:45-51.
- IUCN SSC-CBSG (SPECIES SURVIVAL COMMISSION CAPTIVE BREEDING SPECIALIST GROUP), 1987. 'The IUCN policy statement on captive breeding.' (IUCN: Gland).
- KRETZSCHMAR, A. & ARIES, F. 1992. An analysis of the structure of the burrow system of the Giant Gippsland Earthworm *Megascolides australis* McCoy, 1878 using 3D-images. *Soil Biology and Biochemistry* 24:1583-1586.
- LEES, D. 1989. Practical considerations and techniques in the captive breeding of insects for conservation. *The Entomologist* 108:77-96.
- MALAUSSA, J.C. & DRESCHER, J. 1991. The project to rescue the Italian ground beetle, *Chrysocarabus olympiae*. *International Zoo Yearbook* 30:75-79.
- MORTON, A.C. 1983. Butterfly conservation - the need for a captive breeding institute. *Biological Conservation* 25:19-33.
- 1991a. Captive breeding of butterflies and moths: I. Advances in equipment and techniques. *International Zoo Yearbook* 30:80-89.
- 1991b. Captive breeding of butterflies and moths: II. Conserving genetic variation and managing biodiversity. *International Zoo Yearbook* 30:89-97.
- NEW, T.R. in press. Needs and prospects for insect reintroductions for conservation in Australia. *Proceedings of the Conference on Reintroduction Biology of Australasian Fauna*. 19-21 April 1993, Healesville Sanctuary.
- RIVERS, C. 1990. The control of diseases and pests of insects. Pp. 45-49. In Collins, N.M. (ed), 'The Management and Welfare of Invertebrates in Captivity.' (National Federation of Zoological Gardens of Great Britain and Ireland: London).
- THOMAS, J.A. 1989. Ecological lessons from the reintroduction of Lepidoptera. *The Entomologist* 108:56-68.
- TONGE, S. & BLOXAM, Q. 1991. A review of the captive-breeding programme for Polynesian tree snails. *International Zoo Yearbook* 30:51-59.
- VAN PRAAGH, B.D. 1992. The biology and conservation of the Giant Gippsland Earthworm *Megascolides australis* McCoy, 1878. *Soil Biology and Biochemistry* 24:1363-1367.
- VAN PRAAGH, B.D., YEN, A.L. & LILLYWHITE, P.K. 1989. Further information on the Giant Gippsland Earthworm, *Megascolides australis* (McCoy 1878). *Victorian Naturalist* 106:197-201.
- VAUGHAN, P.J. 1988. Management plan for the Eltham Copper Butterfly (*Paralucia pyrodiscus lucida* Crosby) (Lepidoptera: Lycaenidae). Arthur Rylah Institute for Environmental Research Technical Report Series No. 79, 54 pp.
- YEN, A.L. 1993. The role of museums and zoos in influencing public attitudes towards invertebrate conservation. Pp. 213-229. In Gaston, K.J., Samways, M. & New, T. (eds), 'Perspectives in Insect Conservation.' (Intercept Ltd: Andover, Hampshire).



# THE LONG-TERM EFFECTS OF FIRE ON FOREST ANT COMMUNITIES: MANAGEMENT IMPLICATIONS FOR THE CONSERVATION OF BIODIVERSITY

ALAN YORK

York, A. 1994 06 30: The long-term effects of fire on forest ant communities; management implications for the conservation of biodiversity. *Memoirs of the Queensland Museum* 36(1): 231-239. Brisbane. ISSN 0079-8835.

The long-term impact of fire as an agent of habitat disturbance affecting ant communities was studied in a coastal forest environment. A chronosequence approach utilising sites with understoreys aged between 2 and 14 years post-fire found that ant communities decreased in species richness with time since fire. Data from a control site monitored for 7 years after fire showed similar trends. A substantial proportion of the forests' overall ant richness is, however, contributed by 'rare' species, which are distributed across the full range of forest understorey age classes. Positive management through the prevention of frequent fires and the maintenance of habitat mosaics is required in this area to ensure the conservation of species and the maintenance of biodiversity. □ *Ants, fire, biodiversity, conservation, management, Myall Lakes, New South Wales, Australia.*

Alan York, School of Biological Sciences, University of New South Wales, PO Box 1, Kensington, N.S.W. 2033, Australia; present address: Research Division, State Forests of New South Wales, PO Box 100, Beecroft N.S.W. 2119, Australia; 21 September 1993.

Within natural ecosystems, equilibrium and homogeneity exist only as average conditions on a large spatial and temporal scale. Disturbance is both a major source of heterogeneity in the structure and dynamics of natural communities and an agent of selection in the evolution of life histories (Sousa, 1984). Fire is clearly an agent of disturbance within Australian forest ecosystems, although, as a recurrent component, it has contributed to their development, with highly evolved adaptations exhibited by the flora and fauna. Because eucalypts have characteristics that give good recovery after light to moderate fires, low intensity fires are commonly used as a management tool to reduce the risk of destructive wildfire. In forest environments, a variety of fire 'prescriptions' are used to protect timber resources, promote regeneration, and maintain the diversity of species and habitats (see Underwood et al., 1985; Buckley, 1992).

The aim of this study was to investigate the long-term effect of fire on the richness of forest ant communities. In a management context, an assessment of species richness offers an easily applied method that can establish a base-line from which departures in composition or species abundance can be measured (Main, 1992). It also provides a means of comparing the conservation 'value' of different areas and assessing the impact of management strategies.

There is good theoretical, and growing empiri-

cal evidence to support the role of biological diversity in the maintenance of ecological processes within forests (see Woodward, 1993). This has translated into a growing awareness of the role played by invertebrate groups (both directly and indirectly) in the maintenance of productivity within ecosystems. This has led increasingly to the inclusion of invertebrate conservation strategies within environmental management policies. In addition, because of their abundance and functional importance, certain arthropod groups have a sensitivity and responsiveness to system structure that makes them useful indicators of environmental status and condition (Mattson, 1977). Ants in Australia are ubiquitous, abundant and highly active. They are one of the most important animal groups in terms of energy flow (Brown & Taylor, 1970; Rogers et al., 1972) and the diversity and structure of ant communities is often correlated with the composition of other components of the invertebrate fauna (Majer, 1983). Thus, they are increasingly being used as bio-indicators in a management context (Yeatman & Greenslade, 1980; Majer et al., 1984; Andersen & McKaige, 1987; Burbidge et al., 1992).

## METHODS

The study was conducted in Myall Lakes National Park on the mid-north coast of New South

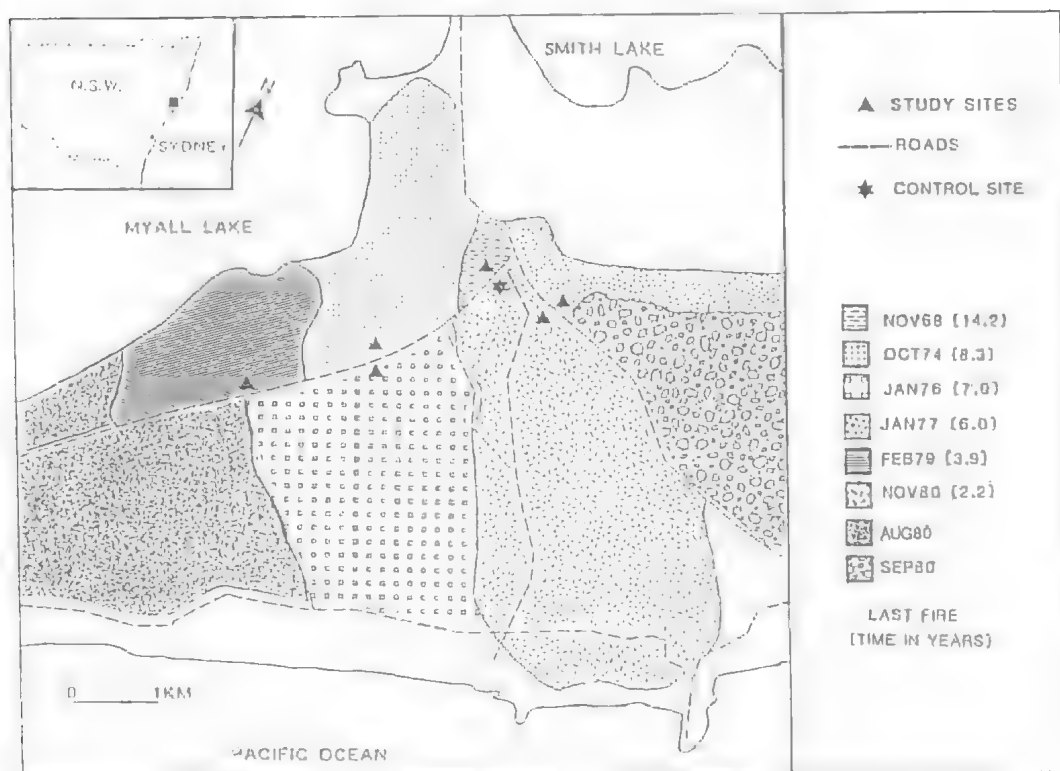


FIG. 1. Location of study sites within fire-induced habitat mosaic, Myall Lakes National Park, N.S.W.

Wales ( $32^{\circ}26'S$ ,  $152^{\circ}32'E$ ) about 300km to the north of Sydney. The study area is isolated from adjacent habitats by two coastal lakes, Myall and Smith (Fig. 1), and is recognised as a single Land System due to its homogeneity (Myerscough & Carolin, 1986). The transgressive dunes support mainly open forest (averaging 26m in height with a projected foliage cover of 62%) with *Eucalyptus pilularis* and *Angophora costata* as dominants. The forest understorey is a rich mixture of sclerophyllous shrubs (Fox, 1981) whose height is a function of time since fire (Fox et al., 1979). The forest was extensively burnt during an intense wildfire in 1968, and has subsequently experienced a high frequency of low-intensity fires, usually during spring and summer. At the time of this study, active fire management by the National Parks and Wildlife Service of New South Wales had resulted in a mosaic of post-fire successional stages within the area, with forest understorey patches ranging from 2.2 to 14.2 years post fire (Fig. 1). The 'natural' fire interval has been estimated as 5-15 years in these forests (Walker, 1981; Fox & Fox, 1986), although increased human usage has shortened this interval considerably in many areas.

The high fire frequency precluded monitoring of a single site and its fauna (particularly under replicate conditions) over a long time period. In this study, the hypotheses that ant species richness does not change in the long term after fire was tested using a chronosequence approach, verified by the monitoring of a control site over time. In order to best approximate a 'time since fire' sequence, a number of study plots were selected so as to minimise non-temporal differences between sites. Plots could be accurately allocated to age classes as detailed fire records had been kept since 1968. Within each understorey age, a 1ha plot was subjectively selected so as to best typify that habitat type, and 4 sub-plots randomly established. Plots had experienced similar fire frequencies and season of burn, had low slope angles ( $0-11^{\circ}$ ) and predominantly north-east to south-east aspects. The use of a large-scale 'natural' experiment such as this prevented effective spatial replication (see Hurlbert, 1984), therefore plots were chosen so that sub-plots reflected the variation apparent at a larger scale within each age class. As part of a related study (see York, 1989), a control site was established and monitored for 6

Site code	Time since last fire (years)	Replicate values (9 pitfalls open for 7 days)				Site values Mean (S.E.)
NOV80	2.2	16	18	21	20	18.8 (1.1)
FEB79	3.9	15	13	18	18	16.3 (1.0)
JAN77	6.1	15	13	10	16	14.3 (1.8)
JAN76	7.0	15	10	13	13	12.8 (1.6)
OCT74	8.3	11	11	12	6	10.0 (1.1)
NOV68	14.2	7	9	8	11	8.8 (1.1)

Time since last fire (years)	Replicate values (9 pitfalls open for 7 days)				Site values Mean (S.E.)
1.1	17	17	19	19	18.0 (0.6)
2.2	19	16	17	15	16.8 (0.9)
3.2	17	17	13	17	16.0 (1.0)
4.2	15	13	14	13	13.8 (0.5)
5.2	16	15	16	18	16.3 (0.6)
6.2	16	14	17	16	15.8 (0.6)
7.2	10	12	14	16	13.0 (1.3)

TABLE 1. Ant species richness on plots differing in time since last fire: Above, chronosequence values; Below, control site values.

years, yielding data from 1.1 to 7.2 years after fire.

Ants (and other epigeic invertebrates) were sampled at each sub-plot using 9 pitfall traps arranged within a 10m×10m grid. Traps were 2.5×15cm Pyrex test tubes fitted in plastic sleeves and sunk flush with the soil surface (after Majer, 1978). The pitfall traps contained 20ml of 70% alcohol (and a few drops of glycerol) and were left open for 7 days during fine weather. For the chronosequence component, sampling was conducted in early February 1983; while sampling at the control site was conducted each February from 1982 to 1988. Samples were returned to the laboratory and examined with a binocular microscope where ants were identified to genus using the key published in Greenslade (1979). A reference collection was established, and final verification of species completed at the National Insect Collection in the CSIRO, Division of Entomology, Canberra. All analytical procedures were performed using the SPSSX statistical package (SPSS Inc., 1983) on the VAX 11-785 computing facilities at the University of New South Wales. Data from the 'chronosequence' and 'control' sites were analysed separately, with regression coefficients from linear regression models compared using the procedure described by Steel & Torrie (1981).

## RESULTS

In excess of 25,000 individuals from 41 ant species were caught and identified during this

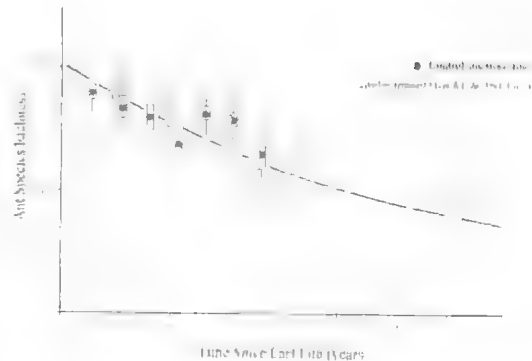


FIG. 2. Changes in ant species richness with time since last fire.

study. These represent primarily surface-active species as certain hypogaeic ant species found by regular soil and litter survey may not be caught in pitfall traps (Majer, 1982). Analysis of the chronosequence data revealed that mean values of ant species richness varied from 8.8 to 18.8, with comparable levels of variability between forest understorey age classes (Table 1). A one-way analysis of variance procedure suggested that ant species richness differed significantly between sites of different ages since fire ( $F=9.50$   $DF=5, 18$   $P=0.0001$ ). Scheffe's multiple-comparison test (Steel & Torrie, 1981) indicated that means of sites closest in age were most similar, with an overall pattern as follows:

TIME SINCE LAST FIRE (years)	2.2	3.9	6.0	7.0	8.3	14.2
MEAN RICHNESS VALUE	18.8	16.3	14.3	12.8	10.0	8.8

(Lines represent means not significantly different at 5% level).

Using regression procedures it was found that there was a significant relationship between ant species richness and time since last fire. Sixty-one percent of the variance in ant species richness was explained by time in the following exponential regression model (see Fig. 2):

$$\text{ANT SPECIES RICHNESS} = 20.34 e^{-0.067 (\text{YEARS SINCE FIRE})}$$

$$r = -0.781 \quad r^2 = 60.9\% \quad n = 24 \quad P < 0.001$$

Although a linear model explained a similar amount of variance (62.8%), it has the limitation of more rapidly predicting the unlikely situation of an environment with no ant species, whereas the exponential model does not predict less than

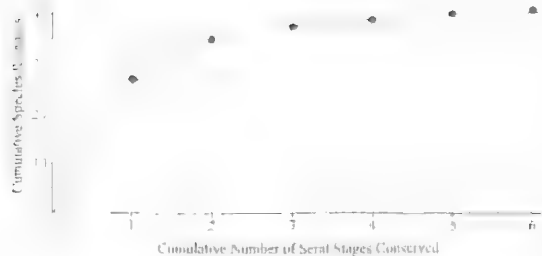


FIG. 3. Increase in total ant species richness with increasing number of habitats conserved.

one ant species for over 46 years after fire. Of the 20,000ha of open-forest in this area, only 3-4ha (0.02%) has remained unburnt for over 14 years. It is unlikely, therefore, that very old sites will persist in this environment, so the linear model would adequately describe the relationship for the most probable situation.

Changes in ant species richness over time at the control site show comparable trends to those described above (Fig. 2), with similar levels of variability (Table 1). Linear regression equations fitted to each data set independently have regression coefficients that are not significantly different ( $F=2.62$   $DF=1,44$   $P=0.12$ ).

These results indicate there is a slow decline in ant species richness in the years after fire. The maintenance of high species diversity in a

management context, however, must include not only a consideration of within-habitat (alpha) diversity, but also between-habitat (beta) diversity (MacArthur, 1965). In an area with a locally high fire frequency, the probability of a patch of forest remaining unburnt decreases with time since last fire, primarily due to the rapid accumulation of fuel (see Fox et al., 1979). If cumulative ant species richness is plotted against the cumulative number of patches of different ages (summed sequentially from youngest to oldest), the relationship takes the form of a species-area curve (Fig. 3). This frequently observed pattern may occur because there is an increase in environmental heterogeneity with increasing area sampled (Williams, 1964), thereby providing new micro-habitats and their component species; or might be related to the relative distribution of individuals among species (Preston, 1948, 1962, 1980), where the rarer species are more likely to be absent from small samples. An examination of the relative abundance distribution of the 41 ant species collected from these habitats (Fig. 4) indicates that rare species constitute the bulk of the ant 'biodiversity' at this scale. Nearly 60% of the species were found in less than 5% of the traps.

These 24 'rare' species are not concentrated in patches of a particular age since last fire (Fig. 5). The number of 'rare' species in any sub-plot is positively correlated with the total number of

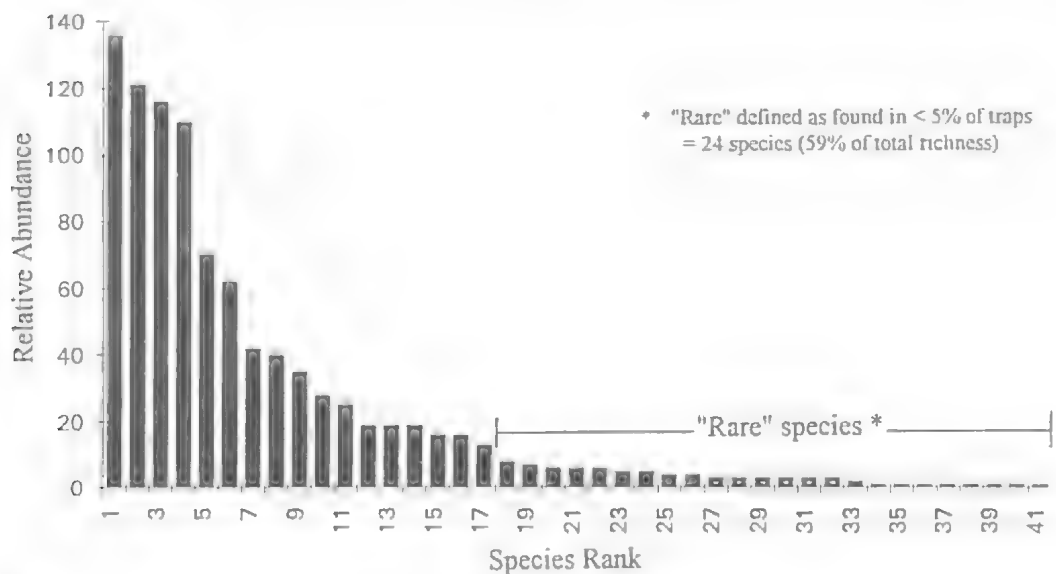


FIG. 4. Forest ant community ranked species abundance.



FIG. 5. Distribution of species considered as 'rare' across sites differing in time since last fire.

species in that sample ( $r=0.766$ ,  $n=24$ ,  $P=0.00001$ ). A closer examination of the distribution of rare species across age classes (Fig. 6) reveals three major patterns. Just under half (11) of these species are found only in one age class, namely: *Brachyponera lutea*, *Cerapachys* sp. A, *Hypoconera* sp. A, *Sphinctomyrmex steinheili*, *Cardiocondyla ?nuda*, *Colobostruma* sp. A, *Lordomyrma ?punctiventris*, *Monomorium* sp. B, *Doleromyrma darwiniana*, *Technomyrmex* sp. A and *Polyrhachis phryne*. Most of these were each found only at one sub-plot and were often represented by 1-2 individuals.

A further 8 species were found across a broad range of sub-plots, but again at low numbers. These species were: *Heteroponera imbellis*, *Aphaenogaster longiceps*, *Mayriella abstinens*, *Mesostoma browni*, *Strumigenys perplexa*, *Camponotus intrepidus*, *Camponotus myopores* and *Paratrechina minutula*. A third group of 5 species were more abundant but found only across ranges of plots of similar age. These species were: *Myrmecia gulosa*, *Mesoponera australis*, *Meranoplus* sp. A, *Myrmicina rugosa* and *Melophorus* sp. B.

## DISCUSSION

In dry sclerophyll forest, fire is perhaps the most important natural source of disturbance. The inherent variability in natural fire regimes results in a mosaic of habitats with vegetation at different stages of floristic and structural post-fire succession. The importance of the structural complexity of the habitat in maintaining ant diversity has previously been reported (e.g. Brian et al., 1976; Boomsma & de Vries, 1980; Greenslade & Halliday, 1983; Andersen, 1986). Fire in this forest environment removes the bulk of understorey vegetation and initiates a pattern of structural habitat change (Fox et al., 1979; Fox, 1988). The

fact that most Australian ants nest are in the soil means they are largely protected from the immediate effects of fire (see Andersen & Yen, 1985; Neumann, 1992). Increases in ant abundance and species richness after fire have been reported, and burnt sites may still show significantly higher values than control plots 18 months after fire (Andersen, 1988).

This study has shown that, in the long-term, ant species richness declines after fire. Sixty-three percent of the variance in ant species richness was explained by a linear regression model with time since last fire as the independent variable. A model developed from chronosequence data predicted that by 7 years post fire, ant species richness would have decreased by 6 to 13 ( $\pm 2.6$ ) species. Species richness measured at a control site 7.2 years after fire was 13 ( $\pm 1.3$ ) species, lending strong support for the model in this forest environment. The richness of the ant community in the long-term is therefore strongly influenced by the fire interval (time since last fire), although the observed pattern could in part reflect a trapping artefact due to increasing habitat complexity over time (see Majer, 1980; Andersen, 1988).

The fire interval represents only one component of the fire regime (see Gill, 1975). However, it has a major effect on the forest community through fuel accumulation, which in turn influences fire intensity (Luke & McArthur, 1978). Although this research suggests that short fire intervals will maintain high ant species richness at a small scale, the management of biodiversity at a large scale must also consider the between-habitat (beta) diversity. Beta diversity is low in these forest habitats, with recently burnt sites supporting the bulk of the overall species richness.

An examination of the relative abundance of species, however, revealed that a substantial proportion (60%) of the overall richness was contributed by species which are uncommon or 'rare'. In studies of community ecology, rare species are often excluded from multivariate analyses because they contribute little to estimation of similarity or interpretation of pattern in the data. In this study, however, a considerable proportion of the overall biodiversity was contributed by these 'rare' or infrequently recorded species. These species were unevenly distributed amongst forest understorey age classes, with the number of 'rare' species being positively correlated with the overall richness at any particular sub-plot. Therefore, for a very high proportion

FIG. 6. Occurrence of 'rare' ant species at sites differing in time since last fire.

Subfamily Species	Years since last fire					
	2.2	3.9	6.0	7.0	8.3	14.2
<b>Myrmeciinae</b>						
<i>Myrmecia gulosa</i>	████████████████					
<b>Ponerinae</b>						
<i>Brachyponera lutea</i>		████████				
<i>Cerapachys</i> sp. A	████████					
<i>Heteroponera imbellis</i>	████████		████████			████████
<i>Hypoponera</i> sp. A				████████		
<i>Mesoponera australis</i>				████████████████		
<i>Sphinctomyrmex steinheili</i>					████████	
<b>Myrmicinae</b>						
<i>Aphaenogaster longiceps</i>		████████		████████████████		
<i>Cardiocondyla ?nuda</i>		████████				
<i>Colobostruma</i> sp. A	████████					
<i>Lordomyrma ?punctiventris</i>						████████
<i>Mayriella (abstinens)</i>	████████		████████████████			
<i>Meranoplus</i> sp. A	████████████████					
<i>Mesostruma browni</i>		████████			████████	
<i>Monomorium</i> sp. B				████████		
<i>Myrmicina rugosa</i>			████████████████			
<i>Strumigenys perplexa</i>		████████		████████		
<b>Dolichoderinae</b>						
<i>Doleromyrina darwiniana</i>		████████				
<i>Technomyrmex</i> sp. A		████████				
<b>Formicinae</b>						
<i>Camponotus (intrepidus)</i>	████████		████████████████			
<i>Camponotus (myopores)</i>	████████				████████	
<i>Melophorus</i> sp. B	████████████████					
<i>Paratrechina minitula</i>	████████		████████████████			
<i>Polyrhachis phryne</i>	████████					
Total number of 'rare' species *	11	10	6	9	7	3
Number of unique 'rare' species	3	4	0	2	1	1

\* 'rare' is defined as those species occurring in less than 5% of traps overall  
 ( ) indicates likely species-group ? indicates most probable species identity

of species, there are insufficient data currently available to confidently predict their response to fire management strategies.

In the context of biodiversity conservation, these may be considered the species of greatest potential concern. While a number of these species showed no pattern as to their distribution — or were found in such low numbers that no conclusions could be drawn — the distribution of a number of species appeared to be linked with forest understorey age. Their rareness is unlikely therefore to reflect a sampling phenomenon but particular habitat conditions.

Some ant species have been shown to have flexible habitat requirements, while others are more specific (see Elmes, 1971; Levins et al., 1973; Chew, 1977; Doncaster, 1981; Majer et al., 1984). These results suggest that, as the habitat changes over time, there is a gradient over which the success, and hence relative abundance, of some species varies. In order to maintain viable populations of these species, and hence conserve them, these coastal forests need to be managed to preserve a mosaic of forest patches reflecting different times since last fire. The structure of these ant communities and the role of micro-habitat will need to be further explored in order to understand the conservation requirements of many of these rare species.

Increased utilisation of prescribed burning for conservation purposes has stimulated interest in prescribing 'natural fire season' burns and, in certain instances, a 'let-burn' strategy (Robbins & Myers, 1992) in which naturally ignited fires run their course. In many coastal forest environments in eastern Australia, high levels of human usage is leading to an increase in fire frequency and a reduction in the complexity of the understorey vegetation mosaic. This research has demonstrated that there is potential for a loss of species with this increasing habitat simplification. With the conservation of biodiversity being a fundamental part of 'multiple-use' forest management (Forest Use Working Group, 1991), fire prescriptions and fire control strategies must be designed to maintain the complexity of habitats on both small and large scales, and therefore maintain the high diversity of ant communities in these environments.

#### ACKNOWLEDGEMENTS

This project formed part of a integrated series of fire experiments conducted in Myall Lakes National Park from 1981 to 1990. I am thankful

to the National Parks and Wildlife Service of New South Wales for permission to work in such pleasant surrounds and for access to fire maps and historical records. Sincere thanks to Barry Fox (UNSW) for his continuing support and advice, Liz Jefferys (UNSW) and Bob Taylor (CSIRO Entomology) for assistance with ant identification, and to the large number of people who willingly assisted with fieldwork over the length of this project. Thanks also to Jonathan Majer and an anonymous referee for constructive comments on an earlier version of the MS.

#### LITERATURE CITED

- ANDERSEN, A.N. 1986. Patterns of ant community organisation in mesic southeastern Australia. *Australian Journal of Ecology* 11: 87-97.
1988. Immediate and longer-term effects of fire on seed predation by ants in sclerophyllous vegetation in south-eastern Australia. *Australian Journal of Ecology* 13: 285-293.
- ANDERSEN, A.N. & MCKAIGIE, M.E. 1987. Ant communities at Rotamah Island Victoria, with particular reference to disturbance and *Rhytidoponera tasmaniensis*. *Proceedings of the Royal Society of Victoria* 99: 141-146.
- ANDERSEN, A.N. & YEN, A.L. 1985. Immediate effects of fire on ants in the semi-arid mallee region of north-western Victoria. *Australian Journal of Ecology* 10: 25-30.
- BOOMSMMA, J.J. & DE VRIES, A. 1980. Ant species distribution in a sandy coastal plain. *Ecological Entomology* 5: 189-204.
- BRIAN, M.V., MOUNTFORD, M.D., ABBOT, A. & VINCENT, S. 1976. The changes in ant species distribution during ten years post-fire regeneration of a heath. *Journal of Animal Ecology* 45: 115-133.
- BROWN, W.L. & TAYLOR, R.W. 1970. Hymenoptera: Superfamily Formicoidea. Pp. 951-959. In CSIRO, 'The insects of Australia'. (Melbourne University Press: Melbourne).
- BUCKLEY, A.J. 1992. Fire behaviour and fuel reduction burning: Benim River wildlife, October 1988. *Australian Forestry* 55: 135-147.
- BURBIDGE, A.H., LEICESTER, K., MCDAVITT, S. & MAJER, J.D. 1992. Ants as indicators of disturbance at Yanchep National Park, Western Australia. *Journal of the Royal Society of Western Australia* 75: 89-95.
- CHEW, R.M. 1977. Some ecological characteristics of the ants of a desert-shrub community in south-eastern Arizona. *American Midland Naturalist* 98: 33-49.



- DONCASTER, C.P. 1981. The spatial distribution of ants nests on Ramsey Island, South Wales, *Journal of Animal Ecology* 50: 195-218.
- ELMES, G.W. 1971. The spatial distribution of two ant species living in limestone grassland. *Pedobiologia* 14: 412-418.
- FOREST USE WORKING GROUP 1991. 'Ecologically Sustainable Development Working Group Final Report — Forest use'. (Australian Government Publishing Service: Canberra).
- FOX, B.J., FOX, M.D. & MCKAY, G.M. 1979. Litter accumulation after fire in a eucalypt forest. *Australian Journal of Botany* 27: 157-166.
- FOX, M.D. 1981. 'Co-existence between eucalypts in a coastal open forest'. (Unpublished PhD thesis, Macquarie University, Sydney).
1988. Understorey changes following fire at Myall Lakes, New South Wales. *Cunninghamia* 2: 85-95.
- FOX, M.D. & FOX, B.J. 1986. The effect of fire frequency on the structure and floristic composition of a woodland understorey. *Australian Journal of Ecology* 11: 77-85.
- GILL, A.M. 1975. Fire and the Australian flora: a review. *Australian Forestry* 38: 4-25.
- GREENSLADE, P.J.M. 1979. 'A guide to the ants of South Australia'. (South Australian Museum Special Education Bulletin Series: Adelaide).
- GREENSLADE, P.J.M. & HALLIDAY, R.B. 1983. Colony dispersion and relationships of meat ants *Iridomyrmex purpureus* and allies in an arid locality in South Australia. *Insectes Sociaux* 30: 82-99.
- HURLBERT, S.H. 1984. Pseudoreplication and the design of ecological field experiments. *Ecological Monographs* 54: 187-211.
- LEVINS, R., PRESSWICK, M.L. & HEATWOLE, H. 1973. Coexistence patterns in insular ants. *American Scientist* 61: 463-472.
- LUKE, R.H. & MCARTHUR, A.G. 1978. 'Bushfires in Australia'. (Australian Government Printing Service: Canberra).
- MACARTHUR, R.H. 1965. Patterns of species diversity. *Biological Reviews* 40: 510-533.
- MAIN, A.R. 1992. The role of diversity in ecosystem function: an overview. Pp. 7-93. In Hobbs, R.J. (ed.), 'Biodiversity of Mediterranean ecosystems in Australia'. (Surrey Beatty and Sons: Sydney).
- MAJER, J.D. 1978. An improved pitfall trap for sampling ants and other epigeic invertebrates. *Journal of the Australian Entomological Society* 17: 261-262.
1980. Report on a study of invertebrates in relation to the Kojonup Nature Reserve fire management plan. Western Australian Institute of Technology, Biology Department. Bulletin No. 2.
1982. Ant-plant interactions in the Darling Botanical District of Western Australia. Pp. 45-61. In Buckley, R.C. (ed.), 'Ant-plant interactions in Australia'. (Junk Publishers: The Hague).
1983. Ants: bioindicators of minesite rehabilitation, land-use and land conservation. *Environmental Management* 7: 375-383.
- MAJER, J.D., DAY, J.E., KABAY, E.D. & PER-RIMAN, W.S. 1984. Recolonisation by ants in bauxite mines rehabilitated by a number of different methods. *Journal of Applied Ecology* 21: 355-375.
- MATTSON, W.J. (ed.) 1977. 'The role of arthropods in forest ecosystems'. (Springer-Verlag: New York).
- MYERSCOUGH, P.J. & CAROLIN, R.C. 1986. The vegetation of the Eurunderee sand mass, headlands and previous islands in the Myall Lakes area, New South Wales. *Cunninghamia* 1: 399-466.
- NEUMANN, F.G. 1992. Responses of foraging ant populations to high-intensity wildfire, salvage logging and natural regeneration processes in *Eucalyptus regnans* regrowth forest of the Victorian Central Highlands. *Australian Forestry* 55: 29-38.
- PRESTON, F.W. 1948. The commonness, and rarity, of species. *Ecology* 29: 254-283.
1962. The canonical distribution of commonness and rarity. Parts I and II. *Ecology* 43: 185-215, 410-432.
1980. Noncanonical distributions of commonness and rarity. *Ecology* 61: 88-97.
- ROBBINS, L.E. & MYERS, R.L. 1992. 'Seasonal effects of prescribed burning in Florida: a review'. Miscellaneous publication No. 8, (Tall Timbers Research Inc: Tallahassee, Florida).
- ROGERS, L.E., LAVIGNE, R.J. & MILLER, J.L. 1972. Bioenergetics of the Western Harvester Ant in the Shortgrass Plains ecosystem. *Environmental Entomology* 1: 763-768.
- SOSA, W.P. 1984. The role of disturbance in natural communities. *Annual Review of Ecology and Systematics* 15: 353-391.
- SPSS INC. 1983. 'SPSSX user's guide'. (McGraw Hill: Chicago).
- STEEL, R.G.D. & TORRIE, J.H. 1981. 'Principles and procedures of statistics. A biometrical approach'. (McGraw Hill: London).
- UNDERWOOD, R.J., SNEEUWJAGT, R.J. & STYLES, H.G. 1985. The contribution of prescribed burning to forest fire control in Western Australia: case studies. Pp. 153-170. In Ford, J.R. (ed.), 'Fire ecology and management

- in Western Australian ecosystems'. (Western Australian Institute of Technology: Perth).
- WALKER, J. 1981. Fuel dynamics in Australian vegetation. Pp. 101-128. In Gill, A.M., Groves, R.H. & Noble, I.R. (eds), 'Fire and the Australian biota'. (Australian Academy of Science: Canberra).
- WILLIAMS, C.B. 1964. 'Patterns in the balance of nature'. (Academic Press: London).
- WOODWARD, F.I. 1993. How many species are required for a functioning ecosystem? In Schultze, E.D. & Mooney, H.A. (eds), 'Ecosystem function of biodiversity'. (Springer-Verlag: Heidelberg).
- YEATMAN, E.M. & GREENSLADE, P.J.M. 1980. Ants as indicators of habitat in three conservation parks in South Australia. *South Australian Naturalist* 55: 20-26,30.
- YORK, A. 1989. 'The response of ant communities to fire-induced habitat disturbance'. (Unpublished PhD thesis, School of Biological Sciences, University of New South Wales).

## CONTENTS

ABLETT, E.M.	An appraisal of RAPD-PCR: a new molecular tool for the identification of invertebrate species . . . . .	1
ABLETT, E.M. & MATTICK, J.S.	Conservation of invertebrate biodiversity: the role of ex situ preservation of genetic material . . . . .	3
BEATTIE, A.J.	Invertebrates as economic resources . . . . .	7
BUTCHER, R.J., CLUNIE, P.E. & YEN, A.L.	The Victorian <i>Flora and Fauna Guarantee Act</i> : Flagship legislation for invertebrate conservation? . . . .	13
BUTTERMORE, R.E., TURNER, E. & MORRICE, M.G.	The introduced northern Pacific seastar <i>Asterias amurensis</i> in Tasmania . . . . .	21
CAMPBELL, A.J. & BROWN, G.R.	Distribution of parasitoids of scarab larvae in relation to remnant vegetation: a preliminary analysis . . .	27
CANNON, L.R.G. & SEWELL, K.B.	Symbionts and biodiversity . . . . .	33
CZECHURA, G.V.	Is the public really interested in invertebrates? What the Queensland Museum Reference Centre enquiries from 1986-1993 tell us . . . . .	41
DANIELL, A.	Genetics and terrestrial mollusc conservation . . . . .	47
DAVIE, P.J.F.	Variations in diversity of mangrove crabs in tropical Australia . . . . .	55
DYNE, G.R. & WALLACE, C.C.	Biodiversity and conservation of the earthworm fauna of the Wet Tropics of Queensland's World Heritage Area . . . . .	59
GREENSLADE, P.	Heritage listing of invertebrate sites in southeastern Australia . . . . .	67
GUILBERT, E. CHAZEAU, J. & BONNET DE LARBOGNE, L.	Canopy arthropod diversity of New Caledonian forests sampled by fogging : preliminary results . . . . .	77
HAYNES, A.	The effects of development on Fijian island freshwater invertebrates . . . . .	87
HOOPER, J.N.A.	Coral reef sponges of the Sahul Shelf — a case for habitat preservation . . . . .	93
HUNT, G.S.	Oribatids — a mite biodiverse . . . . .	107
JELINEK, A., BRITTON, D.R. & NEW, T.R.	Conservation of a 'threatened butterfly community' at Mount Piper, Victoria . . . . .	115
MAJER, J.D., RECHER, H.F. & POSTLE, A.C.	Comparison of arthropod species richness in eastern and western Australian canopies: a contribution to the species number debate . . . . .	121
MARSHALL, J.C.	Photographic identification of stream macro-fauna: a minimally destructive sampling technique . . . . .	132
MESIBOV, R.	Faunal breaks in Tasmania and their significance for invertebrate conservation . . . . .	133

(continued inside back cover)



## CONTENTS (continued)

MILLER, W.R., MILLER, J.D. & HEATWOLE, H.F.	
Tardigrades of the Australian Antarctic Territories: assessing biodiversity within a sample .....	137
NEW, T.R.	
Invertebrate interests in the World Conservation Union's Species Survival Commission .....	147
NEW, T.R.	
Conservation assessment of invertebrate assemblages: is there a place for global level taxon-focusing? .....	153
NEWMAN, L.J. & CANNON, L.R.G.	
Biodiversity of tropical polyclad flatworms from the Great Barrier Reef, Australia .....	159
NICHOLLS, A.O. & MCKENZIE, N.J.	
Environmental control of the local-scale distribution of funnel ants, <i>Aphaenogaster longiceps</i> .....	165
NORTON, T.W.	
An overview of modelling fine-scale variation in environmental regimes in complex landscapes with comments on applications to invertebrate survey, monitoring and conservation .....	173
ORR, A.G.	
Inbreeding depression in Australian butterflies: some implications for conservation. ....	179
PLOWMAN, K.P.	
Stories we tell about fauna .....	185
PONDER, W.F.	
Australian freshwater Molluscs: conservation priorities and indicator species .....	191
SHIELD, J.M. & HARRISON, S.	
Invertebrate biodiversity conservation education: experience with a Bendigo primary school .....	197
SMALES, L.R.	
Parasite extinctions — why care? .....	203
STANISIC, J.	
The distribution and patterns of species diversity of land snails in eastern Australia .....	207
TAYLOR, R.J., MESIBOV, R. & GROWNS, I.	
Local distribution patterns of landsnails in relation to vegetation: implications for reserve design .....	215
WALTER, D.E., O'DOWD, D. & BARNES, V.	
The forgotten arthropods: foliar mites in the forest canopy .....	221
YEN, A.L.	
The prospects of captive breeding for threatened Australian non-marine invertebrates .....	227
YORK, A.	
The long-term effects of fire on forest ant communities: management implications for the conservation of biodiversity .....	231